A

SYLLABUS

OF THE

LECTURES

UPON

EXPERIMENTAL PHILOSOPHY,

DELIVERED AT THE

AGRA COLLEGE.

COMPILED FROM HIS LECTURES BY

JAMES MIDDLETON, F.G.S., F.C.S.,

MEMBER OF THE ASIATIC SOCIETY OF BENGAL, AND PRINCIPAL OF THE HONOURABLE EAST INDIA COMPANY'S COLLEGE AT AGRA.

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PREFACE

TO

THE THIRD EDITION.

1. Many of the Students attending the Experimental Philosophy Class, being but imperfectly familiar with the English language, it was often felt by the lecturer as serious discouragement, that while proceeding with his subject, some of his audience were striving laboriously, and with indifferent success, to keep up with him, whilst others were stumbling on hopelessly behind. In order to overcome this difficulty a Syllabus was drawn up and printed by order of Government, in the beginning of this year, 1848. The work was then much more limited, both in scope and in detail than it is now; it was necessary at the outset to be more elementary too, since the subject was mostly new; at present the Students are apt and ready, and better prepared with elementary knowledge. The first edition was soon exhausted, and a second, enlarged, one was brought out about the end of the following year. The second edition having also become exhausted, the opportunity afforded by my being in England on account of ill health, was availed of to get a third, and still more enlarged, edition printed, which has now been accomplished.

2. It may not be useless, or out of place, to give here a brief sketch of the origin, progress, and expansion of the lectures; since the future historian, who would trace the sources of development and regeneration of the Hindu and Mahomedan mind, may be thereby guided to some of the elements of progress concerned in the result.

3. The lectures were first instituted in 1845, at a time when the apparatus was very defective, and of inferior quality; as it was moreover a rule observed in the College, and rarely it is believed departed from, not to undertake any thing which could not be completely accomplished, they were necessarily at first limited in number and scope. The rule, apart from its general excellence, was, under the circumstances of the students, especially imperative; for it was foreseen that one effect of the lectures, properly directed, must be to undermine that large class of superstitions and errors, prevalent in India, which appeal to natural phenomena misunderstood or misinterpreted, and thus to clear the ground for the dissemination of accurate knowledge and wholesome faith. A result so important could scarce be anticipated from a direct attempt to displace beliefs, inveterate and morticed with habits, feelings, and affections, by other beliefs and startling paradoxes, such as to them must appear natural phenomena or laws, described but not demonstrated. Native Students acknowledge demonstration with candour and alacrity, but are sceptical of mere dogmatism. The inconvenience was not long experienced however, nor the deficiencies of long continuance. The warm interest in the proceedings taken by the Lieutenant

Governor, the Hon. James Thomason, soon enabled the College to possess itself of a Philosophical Apparatus, not surpassed, if equalled, any where else in India, either in respect of completeness or quality. As if still more to mark his approbation of these lectures, and to evince his belief in their usefulness, he caused a theatre to be built and fitted up for their delivery, capable of accommodating 300 spectators.

4. To produce very marked effects upon a people so great in age, so rank in error, so strong in prejudice; when consequently the work of undoing is so heavy, and so essential, must needs have time; but that the lectures have so far realized the expectations formed of them to an important extent, is certain. They are to be heard of any where throughout the North West Provinces; and the College, its apparatus and experiments, have become sights which Indian travellers of all denominations take care to visit. Native artizans now find profitable employment in meeting a growing demand, amongst Native gentlemen of wealth, for apparatus, especially of a galvanic and electrical kind, in the fabrication of which they have become surprisingly skilful. The College Moolvas and Pundits are to be seen unfailing in their attendance at the lectures, and most attentive amongst attentive listeners. One of the Pundits, renowned for his learning and orthodoxy, dwelling one day upon the marvels which he had witnessed, was heard to remark, "Our Gods brought us power, greatness, and goodness; but the English have brought us science."

for its effective discussion, and adequate illustration, are available. It may not be out of place to mention, that throughout the physical course every third lecture day—there being two such days in a week—is devoted to an interrogative lecture, the nature of which is described in the following paragraph.

9. The class being formed, a student is, without foreknowledge on his part, called up in his place, and one or more questions put to him on the subject of the two previous lectures. The answers which he may give are enlarged upon, and extended if necessary, by the Professor, in the familiar manner which this mode of discussion permits; and thus the points in question become more accurately comprehended, perhaps, than during more formal treatment. This process is followed up from student to student, till the lecture hour ends, the subjects having been, in the mean time, all brought under review. Other advantages, too, arise from this plan. The mode of examination, for instance, induces reference and enquiry on the part of most of the students, that they may avoid a display of ignorance and inferiority in the trial of skill with their fellows: while an opportunity is afforded to the Professor, of dwelling upon points which may appear to him to have been not thoroughly developed, or imperfectly understood by his class, during lecture.

10. Care is always taken during the examinations to adapt the scope and difficulty of the question to the student under interrogation. To the dull, or less attentive, most of the small and easy questions are put; the difficult ones being reserved to

the more intelligent. By this management the attention of the former class is kept awake, the intelligence of the latter stimulated, and both encouraged.

11. A few mathematical demonstrations, on important points, not otherwise accessible,—or if so, at least in a form too difficult for the juniors of the class, were thrown together in an Appendix, together with questions bearing on several of the chapters; in the hope that the thought, necessary to the solution of the latter, might assist in familiarising students with the principles involved. The advantages which have arisen from this arrangement have fully answered my expectation. To the more advanced youths the questions furnish entertainment; to the others, occasion for agreeable effort. I soon found, indeed, that more than one had solutions of all the questions ready for the press, and were eager that they should be printed; a proposal which was not however encouraged, since the intellectual exertion, mastery of principles, and self reliance, which unaided and unsuggested solution ensures, would thereby be endangered.

J. M.

London, June, 1857.

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INTRODUCTORY OBSERVATIONS.

1. The interest attending Philosophical Experiments pointed out, as also the importance of such experiments in the communication and enlargement of natural knowledge. Each fact and law, disclosed and demonstrated during this course, should be made the centre of a circle of thought, enquiry, and reflection, else but little good will be derived. The moral obligation students in our colleges are under to assist in the enlightenment of their countrymen. By accepting Government education they enlist themselves in the cause of truth, and become bound to exert themselves in correcting error, uprooting prejudices, and diffusing the information which they themselves receive.

2. The privilege of contemplating aright Natural Phenomena and Scientific Truth. The power these, so contemplated, have to undermine and destroy delusion and error; especially in this country, where much of prevalent superstition rests upon natural phenomena, misunderstood or perverted.

3. The wonder and admiration caused by contemplation of the Heavens. Immense distance of the fixed stars: the largest in the Centaur and Lyra remote from us about 226,000, and 789,000 times the distance of our sun, respectively. Vast number

of comets discovered, some of them revealing, by a diminishing orbit, the existence of a resisting medium in the interstellar spaces. The probability that the stars are suns, the centres of worlds, the abodes of life and happiness, considered.

4. The comparatively small number by whom celestial phenomena are thoroughly understood, and the mystery that still hangs about many of those phenomena. The motive this offers to study and reflection.

5. The Planetary System.—The accessibility of the Planets, comparatively to the fixed stars, as subjects of observation. The remarkable phenomena that some of them present when viewed by the aid of a telescope. The proximate similarity of condition to our earth of the sister planets, and the high probability that they also are inhabited.

6. Remarkable discovery some years ago, simultaneously in England and France, of the planet Neptune. Fact which led to the discovery. Theoretic determination. Prophesy. Fulfilment.

7. The Earth.—Creative wisdom and power manifested therein. The laws which regulate terrestrial phenomena, and the forces by which they are produced, the chief subjects of Experimental Philosophy. The work on Natural Philosophy published by the Society for the diffusion of Useful Knowledge, Dr. Young's Lectures by Kelland, and Golding Bird and Brookes Natural Philosophy, recommended to students for private reading and reference, on the subjects embraced in these lectures.

CHAPTER I.

GENERAL PROPERTIES OF MATTER.

8. The general, sometimes called essential, Properties of Matter are Impenetrability, Extension, Figure, Divisibility, Inertia, Attraction.

9. IMPENETRABILITY.—*Indivisibility of ultimate atoms.* No two particles of matter can occupy the same space at the same time. The necessity of distinguishing between masses or bodies, molecules and atoms. Impenetrability of the particles of liquids considered. Their limited compressibility instanced as evidence of impenetrability in their constituent atoms. The reduction of the gases to the liquid state, and hence the same inference regarding them. The provision observable in this property for the stability of the universe.

10. EXTENSION.—*The property of occupying space* consists of three dimensions,—length; length and breadth; and length breadth and thickness. The two first the subjects of Plane Geometry, the latter of Solid Geometry and of Physics.

11. FIGURE.—*The space contained by and within the surfaces of bodies;* for instance a solid, bounded by a surface every where equidistant from a fixed point within the solid, is of spherical figure, &c. Importance of figure as an element of beauty, both in the organic and inorganic world.

12. Divisibility.—*The susceptibility of unlimited mechanical division.* Ultimate limits of divisibility in bodies. Divisibility as apparent in the organic world. Ehrenberg estimates the thickness of the skin of the Monas Termo at the 64,080,000 part of a line. The dust from the desert of Sahara carried over the Mediterranean to the distance of 1300 miles. The diffusion and permanence of odours. According to Reaumur, the gold plate in embroidery spread over the surface of silver is less than the two millionth part of an inch in thickness; and Dr. Wollaston prepared platinum wire the three millionth of an inch in thickness. A sicca weight of spider's web would extend 800 miles, or three sicca weights (540 grs.) would go round the earth, while the thread itself has been said to consist of not less than 6000 filaments. If the filaments were separated and placed end to end, a sicca weight would be 4,800,000 of miles in length, and would thus go round the earth 200 times, or stretch into space 20 times as far as the moon.

13. Inertia.—*Resistance to change of state either of rest or motion.* Illustrations. Revolution of the moon around the earth illustrative of this property. The permanency of planetary motion secured thereby.

14. Attraction.—*The power which particles of matter have of mutually drawing each other.* Different kinds of attraction.

15. Attraction of Gravitation.—*This kind of attraction manifested in the fall of bodies towards the earth.* Reason why our earth does not also appear to move in such cases. Manifestation of the attraction of gravitation in the motion of the earth and other planets around the sun, and of the moon around the earth. Operation of gravitation on the atmosphere.

16. Attraction of Cohesion.—*This kind of attraction is mani-*

fested in the tenacity with which the parts of bodies, of those called solid bodies, especially, hold together. Exists in least intensity in liquids, while in the gaseous condition of bodies its operation seems to be entirely suspended. Necessity of this property to the continuance of form and life.

17. Capillary Attraction.—*The attraction exerted by the interior walls of fine tubes.* Illustrated by the ascent of coloured fluids in tubes of different sized bores. Seems to be due to the attraction of the walls of the tube. Liquids so raised may arrive at the top of the bore, but cannot run over. Form of the upper surface of capillary columns of liquid. The law of the heights is, *the heights are inversely as the bores of the tubes.* The ascent of sap in vegetables, and hence provision for organic life, dependent on this property.

18. Magnetic Attraction.—*The power possessed by magnets,* natural or artificial, permanent or temporary, *of drawing certain bodies,* such as iron, *towards them.* Illustrations by means of natural and artificial magnets.

19. Porosity.—*Possession of interstitial spaces.* Seen well in the sponge, in which some of the interstices are very large, some too small to be seen. Water has been driven through the pores in the walls of gold vessels; light passes through thin gold plates; and water is filtered, for purification, through stone. The bones as well as the soft parts of men and animals are permeated throughout life by liquids; the vehicles of nutriment. I have proved that the excess of fluoride of calcium in fossil bones arises from infiltration after death. In liquids porosity is evident in processes of solution; in gases by diffusion, and is inferrible from their high compressibility.*

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* See *Philosophical Magazine* for October and November, 1854.

CHAPTER II.

REST AND MOTION.

20. *The condition of a body under the operation of balancing and of non-balancing forces*, or what is ordinarily designated by the terms rest and motion; the former condition being the resultant of forces that balance each other, and the latter of those that do not. *Rest* and *motion* relative terms only. No body absolutely at rest.

21. Incapability of spontaneous motion necessary for the purposes which matter has to subserve, it being thus easily controlled by natural forces. The harmony of the universe dependant on this property.

22. Particles subject to unceasing influences from other particles around them; as those of which the earth is composed, to one another, and to central forces. The attraction of proximate particles neutralized, within certain limits, by their antagonism. Fluids and liquids are exposed to constant and various impurity, which would endanger the health, and render the existence of animal life precarious, were the evil not remedied by the ceaseless internal motion to which they are subject.

23. All bodies subject to the action of an infinite number of forces,—those that are in motion as well as those that are at rest.

24. *Rest of a point.* Three simplest cases, the forces acting in the same plane, described and illustrated by experiment, viz.—

1st. *A point acted on by two forces.*

2nd. *A point acted on by three forces.*

3rd. *A point acted on by any number of forces.*

25. *Representation of forces by lines.* In respect of magnitude. In respect of direction. Components. Resultants.

26. *Parallelogram of Forces.* If a point be acted on by two forces, represented in magnitude and direction by two adjacent sides of a parallelogram, the balancing force, or resultant, will be represented in magnitude and direction by the diagonal of the parallelogram.

Note. If the two forces act upwards the balancing forces will act downwards, and so on.

27. If in a polygon, the sides, less one, represent a corresponding number of forces in magnitude and direction, the remaining side represents the balancing force.*

Cor. If any number of forces, acting upon a point, be proportional and parallel to the sides of a polygon, the point will be at rest.

28. *Decomposition of Forces.*

1st. To replace one force by two, whose joint effect shall equal that of the original force.

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* Appendix, Note A.

2nd. To replace one force by any number of forces, whose effect shall equal that of the original force.

Demonstrations, by means of the inclined plane, on the resolution of forces.

Note. Any one or more of the sides may be taken as resultant, as convenience may suggest.

29. *Motion of a point.* Discussion corresponding to that for rest of a point.

30. The attraction exerted by a body is as its mass, that is as the quantity of matter of which it is made up; since any one molecule exerts a power independently of the others with which it may be associated, and, so far as is yet known, irrespective of its nature. Our perception, that bodies near the earth's surface do not exert any force to attract the earth towards them, not strictly accurate. Comparative masses of bodies, ordinarily subject of observation, and that of the earth, considered.

31. *Mass, how measured or estimated.* The unit of mass differs in different countries.

In England the unit is the pound Troy.
In France „ the pound of 500 grammes.

BASES OF METRICAL SYSTEMS.

In England, the base is the length of a pendulum vibrating seconds in the latitude of London, at the sea level and in vacuo; this is found to be 39·1393 inches long: otherwise an inch is $\frac{1}{39 \cdot 1393}$th part of such pendulum.

In France, the base is a forty-millionth part of the terrestrial meridian,—and is called a metre:—it is equal to 39·37079 English inches. The subdivisions are—

10 Decimetres	=	1 Metre
10 Centimetres	=	1 Decimetre
10 Milimetres	=	1 Centimetre

32. *Momentum.* If B be any body in motion, M the momentum or moving force of the body, n the number of particles of which it is made up, and V the velocity of a single particle, the moving force of B is given by the equation

$$M = n\,V$$

33. The moving force of a body being dependent upon its mass and velocity, we deduce the three following laws:

I. *Bodies that have equal velocities and equal masses have their moving forces equal.*

II. *Bodies that have unequal velocities and equal masses have their moving forces unequal.*

III. *Bodies that have unequal masses, and velocities such that the products of the masses into the velocities are equal, have their moving forces equal.*

Experiments illustrative of these laws, with their several modifications due to elasticity, by means of clay and ivory balls, falling through equal and unequal heights, and impinging upon each other.

34. Tendency of all bodies towards the Earth's centre. Weight is an exponent, and the fall of bodies a manifestation of this tendency.*

EXPERIMENTS.

First. A piece of iron is placed in a vessel containing quicksilver; the iron is seen to float.

Second. A gold mohur and a feather are allowed to fall simultaneously in the exhausted receiver of an air-pump; they are seen to reach the bottom together.

* Appendix, Note B.

The second Analysis where

$$V = 2sT$$

Shows that,

The velocities acquired by bodies falling freely, during any time, are sufficient to carry them through twice that space in the same time.

The third Analysis in which

$$S = s\,T^2$$

Shows that,

The spaces described by bodies falling freely are as the squares of the times of describing them.

The fourth Analysis in which

$$S : S' - S : S'' - S' :: 1 : 3 : 5$$

Shows that,

*The spaces described in successive units of time, by bodies falling freely, are as the odd numbers.**

36. Bodies falling freely descend through 16·08 feet in the first second of their fall: substituting this in the equation for the velocity, we obtain

$$V = 32{\cdot}16\,T$$

The number 32·16, being the effect produced by the earth's attraction at the sea level, in the unit of time, is taken as the *Unit of velocity due to gravity*, and is generally represented by the letter g.

Substituting this in the above equation we have

$$V = gT$$

Substituting the same value in the Equation for the space, we get

$$S = \tfrac{1}{2}gT^2$$

* Appendix, Note D.

Again, substituting p for g, for greater generalitity, we get

$$V = pT. \quad S = \frac{pT^2}{2} \text{ or } = \frac{V^2}{2p}$$

37. If there be an initial constant motion C, the effect of a uniformly accelerating force will not be disturbed thereby, and the equations will then become

$$V = C + pT$$
$$S = CT + pT^2$$

Eliminating p we get

$$S = \frac{C+V}{2} . T$$
$$= \frac{V^2 - C^2}{2p}$$

38. If the force be a retarding one the initial motion will be diminished thereby, and the equations will become.

$$V' = C - pT'$$

$$S' = cT' - \frac{pT'^2}{2}$$

$$= \frac{C+V'}{2} . T'$$

$$= \frac{C^2 - V'^2}{2p}$$

39. In the case of gravity, if a body be projected upwards to a certain height, or dropped from the same height,—the velocities at the end and beginning of the motion, is zero; which gives

$$T = -T'$$

Hence we deduce that

The time of ascent of a body projected upwards to a given point, is equal to the time of its descent from the same point.

$$\text{Again } T = -T' \text{ gives}$$
$$V = V'$$

Hence, *the velocities of a projectile at the same heights are equal, going and returning.* A body, projected upwards, returns to the ground therefore with the velocity with which it left it.

40. Law of intensity of Centripetal force: *The inverse square of the distance from the attracting centre.*

It is proved by Geometry that the attraction of a spheroid is the same as if the attractions of its constituent molecules were collected in its centre of gravity. Now a series of concentric spherical surfaces of different radii, (and all distances from the centre may be viewed as points in such surfaces,) will have the attractive force emanating from the centre strong or feeble according as the areas of the surfaces over which it is diffused be small or great; but these areas are as the squares of the radii of the surfaces, therefore the intensity of the attractive force at any point in them will be inversely as those squares; *i.e. as the squares of their distances from the attracting centre.* The force of gravity at 4000 and at 8000 miles from the earth will be $\frac{1}{4}$ and $\frac{1}{9}$, respectively, what it is at the surface, and so on. For the distances from the centre will be 2r or 3r, the squares of which are as 4 and 9, and the inverse of the squares $\frac{1}{4}$ and $\frac{1}{9}$.

PENDULUMS.

41. Gravity availed of in the application of pendulums, to the regulation of clocks, &c. The *simple pendulum.* The *compound pendulum.* Oscillation. Amplitude. Isochronism. The law connecting the time and length is,

$$T = \pi\sqrt{\frac{l}{g}}$$

T is the time of a complete oscillation.

l length of the pendulum.

π, as usual, the ratio of the diameter of a circle to its circumference.

g the effect of gravity in a unit of time.

If n be the number of oscillations made by a pendulum in 24 hours

$$T = \frac{24 \times 60 \times 60}{n} = \pi \sqrt{\frac{l}{g}}$$

which gives n.

Cavendish's pendulum; its construction and use, also the results at which he arrived by its means. Invariability of plane of oscillation of the pendulum. Foucault's application of this principle. Geometrical demonstration.

Experiments.

First. A pendulum consisting of a large sphere of wood, painted yellow on one side and black on the other, suspended from the roof of the theatre, is drawn to one side and then allowed to fall, consequently to oscillate.

Second. The bob of the same pendulum is projected horizontally, and is seen to move in an elliptical orbit, at the same time revolving on its own axis; showing, rudely, the annual and diurnal revolution of the earth.

Third. A pendulum, suspended within a vertical arch capable of horizontal rotation, is made to oscillate: it is found that the plane of oscillation remains the same, though the arch be made to rotate.

Fourth. A pendulum, consisting of a sphere of brass (about two pounds in weight) is suspended from the roof of the college by a fine wire: it is provided at its lowest part with an index, and is made to oscillate over a line, traced on a circular board graduated round the edge. The plane of oscillation is found, on the expiry of half an hour, to make an angle of about 3¼ degrees with the initial plane of motion.

CHAPTER IV.

CENTRIFUGAL FORCE.

42. Centrifugal Force opposed to Centripetal Force: the latter draws bodies towards a centre, the former repels them from it. Centrifugal force non-existent in bodies at rest; nor in those in motion, unless they revolve round a centre,—it being the resolved part of the tangential force, in a direction from the centre of the orbit. The centrifugal counteracted by the centripetal force, therefore equal to it in amount, and opposite to it in direction. Exhibits itself in the tension of a loaded sling, when whirled round by the hand—in the dashing away of mud from the wheels of carriages in rapid motion, in the swinging of a glass of water round, by means of a sling, without spilling the water, &c.

The Whirling Table.

EXPERIMENT.

A ball is attached to a string passing through the hollow axis of the Whirling Table. The table being made to revolve causes the ball to recede from the centre, stretching the string with a force proportioned to the angular velocity of the table. The angular velocity of the ball increases as the ball is made to approach the centre.

43. Effect of the increase of angular velocity, as the centre is approached, upon the stability of planetary orbits, considered.

44. The magnitude of centrifugal force at the earth's equator considered. Velocity of bodies on the surface at the equator measured by nearly 25,000 miles a day, or 510 yards in a second of time. Effects of this on the material of which the earth is composed. Consequences if the antagonist force were to cease with respect to the earth and to the Solar System.

45. The energy of centripetal force greatest at the poles, where it is unopposed by centrifugal force, and least at the equator, where that force is the greatest. A body weighed with a spring balance, at the equator and at the poles, would have different weights, being heavier at the latter than at the former place. The pendulum, which owes its motion to the force of the earth's attraction, would oscilliate faster at the poles than anywhere else, and most slowly at the equator.

46. The greater centrifugal force at the equator should cause the earth, if originally a sphere, to bulge out at the equator. The earth's equatorial diameter greater than its polar diameter by $\frac{1}{300}$ part of the former, say $26\frac{1}{2}$ miles. This consequence foreseen by Newton, the discoverer of the functions and laws of central forces, and the amount of departure from the spherical form computed by him. Prime object of Trigonometric Surveys to determine accurately the form of the earth. Singularly close approximation of the results of such surveys, and the deductions from theory by Newton.

EXPERIMENT.

A hoop, free to contract and expand in the direction of its polar axis, is whirled rapidly round, when its polar diameter is seen to diminish and its equatorial to extend, in quantities which are functions of the velocity.

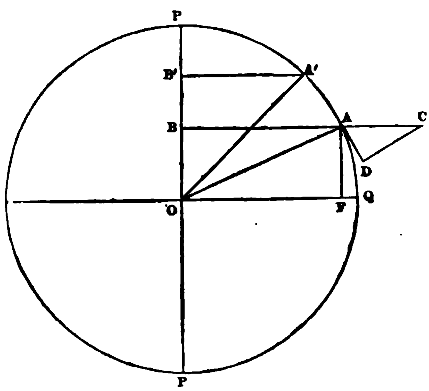
47. The figure described by the hoop in the last experiment is clearly seen, and is distinctly oblate spheroidal. The earth

viewed as made up of an infinite number of such hoops. Spheroidal form of the whole mass inferred from such view.

EXPERIMENT.

Equal weights are simultaneously whirled round with unequal velocities; in that which has the greater velocity the greater centrifugal force is manifested.

48. The polar axis is the common axis of rotation of all the particles of which the earth is made up. In the annexed figure



OQ is obviously greater than AB, AB than A′B′ and so on. These lines are evidently as the cosines of QA, QA′, *i.e.* of the latitudes. Let F, F′ be the centrifugal forces, and l, l', the latitudes at Q, a point at the equator, and at A any point remote from it, respectively; we have

$$F : F' :: \cos. l : \cos. l'$$

$$\text{Hence } F' = \frac{F \cos. l'}{\cos. l}$$

but at Q, $\cos. l = 1.$

$$\therefore F' = F \cos. l'$$

Now F is ascertained to be $\frac{1}{289}$ part of gravity.

Substituting, we obtain a general expression for the centrifugal force at any point of the earth's surface, viz.

$$F' = \frac{g}{289} \cos. l' \ldots\ldots (A)$$

49. Produce BA to any point C; draw AD a tangent at A, and let fall upon AD a perpendicular from C. If AC be taken to represent the total centrifugal force at C, CD represents the portion of that force opposite to gravity, AD a portion acting in a direction tangent to the earth's surface at A. The latter portion tends to accumulate matter about the earth's equator, to produce oceanic currents from the poles, &c. The relative values of the decomposed parts of the centrifugal force are as follows:

$$CD : CA :: OF : OA$$

$$\therefore CD = \frac{CA.OF}{OA} = CA \; cos. \; l$$

$$= F \; cos. \; l$$

Substituting the value of F, from (A), we obtain for the part acting in opposition to gravity

$$CD = \frac{g}{289} \; cos.^2 \; l \ldots\ldots (B)$$

For the tangential part we have

$$AD^2 = AC^2 - CD^2$$

$$= (\frac{g}{289} \; cos. \; l)^2 - (\frac{g}{289} \; cos.^2 \; l)^2 \ldots \text{from (A) \& (B)}.$$

$$= (\frac{g}{289} \; cos. \; l)^2 \, (1 - cos.^2 \; l)$$

$$= (\frac{g}{289} \; cos. \; l)^2 \; sin^2 \; l$$

$$\therefore AD = \frac{g}{289} sin. \; l. \; cos. \; l$$

Experiments.

First. Unequal masses are placed at equal distances from the centre, and are attached to equal weights; they are then made to revolve, and the greater raises its weight while the lesser remains undisturbed.

Second. Equal masses are placed at unequal distances from the centre, and are attached to equal weights; they are now made to revolve, when the more remote mass raises its weight, that of the other remaining undisturbed.

Third. Equal masses are placed at equal distances from the centre, and attached to equal weights; they are now made to revolve, when both raise their weights simultaneously.

Fourth. Equal masses are placed at unequal distances from the centre, and are attached to weights which are to one another as the distances; they are now made to revolve, when both raise their weights simultaneously.

Fifth. Two masses are placed at distances from the centre, which are inversely as the masses, and are attached to equal weights; they are now made to revolve, when it is found that the weights are raised at the same time.

Cor. The sun and earth revolve round each other and about a common centre, distant from these, inversely as the masses; hence it is $\frac{1}{3300}$ of the sun's diameter distant from his centre, *i.e.* about 267 miles.

Note. In the above experiments the periods of revolution of the bars, bearing the masses, are equal: in the following they are as one to two.

Sixth. Two equal masses are placed at equal distances from the centre, and attached to weights which are as 4 : 1—the first term applying to the weight connected with the mass on the swifter bar: they are now made to revolve, and are found to raise their weights simultaneously.

Seventh. Equal masses are placed at 2 inches and 3·2 inches from the centre on the swifter and slower bar respectively, and are attached to equal weights: they are now made to revolve, when they are found to raise their weights simultaneously.

50. From the above experiments we deduce the following Laws:—

I. *The greater the quantity of matter in any body is, the greater is its centrifugal force.*

II. *The greater the velocity of any body is, the greater is its centrifugal force.*

III. *Bodies whose masses and whose velocities are equal, have the same centrifugal force.*

IV. *When the masses are equal, and the periodic times are also equal, the forces are as the distances from the centre.*

V. *If the masses be in the inverse ratio of the distances from the centre, the forces are equal.*

VI. *The forces are inversely as the squares of the periodic times.*

VII. *The squares of the periodic times are as the cubes of the distances from the centre.*

51. The noble proof of the theory, that central forces are the true cause of planetary motion, afforded by the discovery by Leverrier and Adams of the planet Neptune.

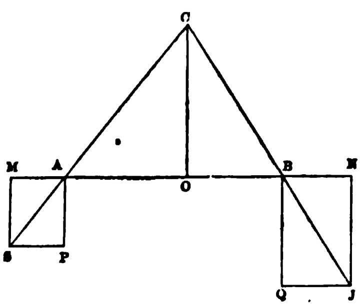
Note. The seventh law is that known as the third law of Kepler, while the first law of Kepler,—*The equality of the areas described in equal times by the radius vector of a planet's path,* is to be inferred from the experiment described at p. 16.*

* Appendix, note E.

CHAPTER V.

CENTRE OF PARALLEL FORCES.

52. The term applied to a point in a body, or system of bodies acted upon by parallel forces so situated that, if a certain force be applied to it, that force will balance, or hold in equilibrium, all the other forces acting upon the system.



53. Let AP, BQ be two parallel forces acting on the rigid line AB. Apply at A and B two equal and opposite forces AM, BN, these will not disturb the equilibrium. Complete the parallelograms AS, BJ, and produce the diagonals till they meet in C; then is C the point of concurrence of the compound forces AS, BJ; hence their resultant, that is the resultant of AP, BQ—since PS and QJ being equal and opposite, balance each other—must pass through that point. Draw CO parallel to the direction of the given forces. If the forces AP, BQ, be transferred to O they will coincide, and their direction will pass through C; hence O is the point of application of the resultant, which will be obviously equal to their sum;

moreover, if they both act in the same direction; or to their difference, if they act in opposite directions. O is called the centre of the parallel forces AP, BQ.

The intensity of the resultant R is given by the equation

$$P + Q = R$$

Again, we have from similar triangles

$$\begin{aligned} CO &: AO :: AP : PS \\ OB &: CO :: QJ\ (PS) : QB \\ \therefore OB &: AO :: AP : QB \\ &:: P : Q. \end{aligned}$$

Law. The centre of parallel forces in the case of two forces is situated between them, and at distances from them which are inversely as the intensities of the forces.

54. The centre of any number of parallel forces may be found thus. Find as before the centre of any two of the forces, and the intensity of their resultant. Proceed in the same manner with this resultant, considered as a new force, and one of the remaining forces, and so on. The centre last obtained is the centre of the parallel forces of the system. It obviously matters not to this result what the direction of the forces may be, so long as they maintain their parallelism and relative intensities.*

Centre of Gravity.

55. *Gravity*, or the force of the earth's attraction, gives to bodies that tendency downwards which they generally manifest, and which is ordinarily called weight. Gravity acts, in parallel directions, and with an equal intensity, on all the constituent par-

* Appendix, note F.

ticles of small bodies. The centre of parallel forces called in this case the centre of gravity.

56. Gravity acts on bodies with an intensity which is a measure of the quantity of matter they contain. The relation of the weight to the mass of a body is expressed by the equation

$$W = Mg$$

57. Gravity acts in the vertical, hence the resultant of forces exerted by it also lies in the vertical. A heavy body, freely suspended by a string, will have its centre of gravity in a line the direction of which is that of the string. If a body be suspended from different points in succession, the directions of the string will intersect in the same point. The centre of gravity of a body practically found by this means. If a flat body, as a board, be laid along the edge of a table so as just to balance there, and a line be drawn on the surface of the body along the edge of the table, and if the same be repeated for different situations of the body, the lines will intersect in the same point. This point will be the *Centre of Gravity of the body.*

Experiments.

First. Determination of the centre of gravity of a cylindrical rod.

Second. Determination of the centre of gravity of an elliptical board by the method of suspension.

Third. Of the same by balancing on the edge of a table.

Fourth. Determination of the centre of gravity of a metallic hoop.

Fifth. Stable and unstable equilibrium under suspension.

Sixth. The same during rest on a horizontal surface.

Seventh. Experiments with rectangular and oblique parallelopipeds. Stable or unstable equilibrium produced by increase or diminution of elevation of an oblique parallelopiped. Discussion of the experiments.

58. Considerations on the centre of gravity in motion. The *Line of Direction*, in bodies falling freely, perpendicular to the surface of the earth.

Experiments.

First. A disc, loaded at one part of the edge with lead, is made to advance up an inclined plane.

Second. A double cone is made to run up two adjacent diverging planes.

59. Consequences of the resultant falling without the base of support—the feet, for instance, in men and animals. Management of the centre of gravity in walking. Experience, in this case, assumes the form of instinct. Corpulent men, and men carrying weights in their arms, lean backwards; those carrying loads on their backs lean forwards. Rationale of this.

Deductions from the above Experiments.

First. If the resultant fall within the base of the body, the body will rest.

Second. If the resultant fall without the base the body will fall.

Third. If the resultant coincide with the edge of the base, the equilibrium will be unstable, and the body will be upset by the least disturbance.

Fourth. If a body have its centre of gravity situated above the point of suspension, the equilibrium is unstable.

Fifth. If a body, freely suspended, have its centre of gravity in the vertical, and below the point of suspension, the equilibrium is stable.

Sixth. A body free to move, may be made to run up an inclined plane, provided that the centre of gravity descend as the body advances.

60. The centre of gravity of a man with wooden legs, describes, while he walks, a series of circular arcs—that of a man running, a series of parabolic arcs. Limit to the speed of the former about 7 miles an hour.*

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* Appendix, Note G.

CHAPTER VI.

HYDROSTATICS.

61. Characteristic properties of fluid bodies. Important part they play as constituting seas, oceans, rivers, rain, dew, the atmosphere, &c. The subject revolves itself into two branches —the consideration of the properties of fluids, but little elastic, such as water; and of those highly elastic, such as air. The former called *liquids*, the latter *gases*.

LIQUIDS.

62. Water serves as a type of liquids generally, due allowance being made for density, viscosity, &c. Taken as the standard of weight, one cubic inch, with suitable restriction in respect of temperature and pressure, (to be considered hereafter,) weighs 252·5 grains troy.

Experiments.

First. A syphon tube has mercury poured into it. The mercury stands at the same level in both limbs of the tube; other liquids are found to do likewise.

Second. A syphon tube has mercury poured into one limb and water into the other. The column of water is found to be about fourteen times the length of the column of mercury. A similar result is obtained on balancing other dissimilar and immiscible fluids.

Third. Arrangement for the hydrostatic paradox shows that the *quantity* of liquid is not concerned in such results.

63. We deduce from the experiments just described the following laws:—

First. Liquid columns, of equal densities, exert pressures proportioned to their heights.

Second. Equal fluid columns of different densities, exert pressures which are directly as their densities.

Third. Fluid columns, of different densities, exert pressures which are as the product of their heights and densities.

64. Fluids are in ceaseless motion, so far as their constituent particles are concerned. The disintegration of rocks, the formation and decomposition of animal and vegetable substances, the crystallization of metals, &c. show a similar restlesness, in and among solid bodies. Masses of fluid, though at rest on the whole, with respect to other bodies, are not so, in so far as the particles of which they are individually made up are concerned. Vortices in drops of liquids, as seen by the aid of the microscope. Motion of water, as constituting rivers, oceans, and seas, adverted to. Essential importance of this ceaseless activity in fluids to the life of animals inhabiting them.

65. Liquids have sufficient cohesion to acquire, and sustain, the form of drops, as in rain, water poured out, &c. Illustration with mercury poured upon glass. In gases there is no such cohesion, but on the contrary, repulsion. Water formed by the union of two gases, Oxygen and Hydrogen, in the proportion of 8 to 1. Water may be composed and decomposed from and into its constituent gases, by means of electricity. Experiment demonstrates this.

66. Water, both compressible and elastic, diminishing one-twentieth of its bulk at the depth in the sea of 1000 fathoms.

Mode in which such experiments have been made. Oersted finds the compressibility a 46 millionth of the bulk for a pressure of an atmosphere; and Regnault has shewn that the compressibility diminishes as the temperature increases.

67. Fluids press equally in all directions. One portion of fluid, whatever be its form, will support any other portion of the same fluid at the same altitude above the horizontal plane. The Hydrostatic Paradox.

EXPERIMENTS.

A number of tubes, straight, crooked, and curved, intercommunicate at their lower ends; water poured into one rises to the same height in all simultaneously.

68. Safety of steam boilers provided for by means of the safety valve, on the principle of equality of pressure of fluids in all directions. Arrangement for this purpose described.

69. Comfort of living things, on the earth and in the sea, dependent on this property of fluids. The impossibility of the existence of submarine animals, having to support the weight both of air and water, under other circumstances than those adverted to. Amount of fluid pressure at the surface of the earth, and at certain depths in the sea.

70. Pressure of fluid columns continued. A portion of fluid, however small, is capable of supporting any other portion however great. Description of the Hydrostatic Bellows, and experiments therewith.

71. Conditions of equilibrium in the bellows, given by the equation

$$W = \frac{K}{k} Q$$

where W is the weight raised by the water, *i.e.* the pressure exerted by it, Q the pressure due to the column of water in the tube of the bellows, K the area of the surface of the bellows, and *k* the area of a section of the tube. It is evident that W increases by the increase of Q or K, and the decrease of *k*. Description of Brahma's press, and of some of its economical uses.

Centre of Pressure.

72. The centre of pressure of a fluid against a containing vessel or sluice. Its situation. A support applied at this point is more efficient than if applied at any other point.*

Levelling.

73. Surfaces of small portions of fluids are horizontal, accurately so for all practical purposes. In large portions, such as seas, the surface is curved, equally throughout. The surface of the sea taken as a zero point for the altitude of mountains. The property of fluids, of finding their level, availed of in the construction of surveying and astronomical instruments. Alcohol usually employed for levels, being introduced into a tube slightly curved, and which is nearly filled with it; the small vacancy left ordinarily called the bubble. Reason for the particular liquid, and for the curvature of the tube.

74. Care to be taken, in using such instruments, that the convex part of the tube be kept uppermost, else the level will become unmanageable; the bubble in such a case always flying to either end. The construction of levels for engineers and others, and their modes of use explained and demonstrated by means of models and instruments.

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* Appendix, Note H.

Principle of Archimides.

75. *A body immersed in a fluid loses a portion of its weight, equal to that of the fluid displaced.*

Specific Gravity.

76. Specific gravity is the gravity or weight special to bodies. In practice specific gravity is *the relation between the weights of equal masses of substances and of some substance whose weight is known, and under the same conditions, constant.* The usual standard employed, distilled water; it being free from impurities, and, for the same temperature and atmospheric pressure, invariable.

Specific Gravity of Solids.

The specific gravity of solids is obtained, by dividing the weight of the given solid, as weighed in air, by the weight which it has lost when weighed in water.

77. Difference between the specific gravity of the same body, as weighed in pure and impure water. Experiment in proof of this.

Specific Gravity of Fluids.

78. The specific gravities of Fluids are found—

First. By filling a bottle with the given fluid and then with the standard fluid, and determining the proportion of the weights in either case.

Second. By ascertaining the relation of a solid to the given fluid, and to the standard fluid.

Third. By means of the Hydrometer.

79. The construction of different Hydrometers described, and their uses demonstrated.*

* Appendix, Note I.

GASES.

80. Atmospheric air may be adopted as the representative of elastic bodies of the fluid kind generally, as water of the non-elastic. Gases, heretofore considered permanent, reduced to liquids by Professor Faraday, with the exception of three. Gases, thus condensed, become subject to the laws governing liquids, from which, in this condition, it is unnecessary to separate them. The remaining gases will doubtless be condensed some day.

Mariotte's Law.

81. *The elastic force of air, at a given temperature, is inversely as the space it occupies.*

82. The elastic force of air increases with the temperature. A given mass expands 0·0003665 of its bulk between 0° and 100° centigrade: for different gases the coefficient differs. At very great pressures the elasticity seems to abate, relatively to the law.

Experiment.

A bent tube of unequal limbs has the shorter limb sealed. When filled with mercury to different heights, the air in the sealed limb is compressed according to the law ennunciated.

83. Atmospheric air, at the earth's surface, subject to a pressure of 15 lbs. to the square inch, equal to the pressure of a column of mercury of 30 inches. In a Mariotte's tube of 60 inches if the open limb be filled with mercury, the air in the sealed one will be compressed to one-half its bulk.

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† See *Elements de Physique, par M. Pouillet*, sixth edition, p. 301, vol. 1.

84. The property of the vapour of water being condensed by ordinary temperature, of great importance in nature and in the arts. Ceaseless ascent of the vapour of water into the atmosphere. The number of gallons raised by evaporation from an acre of water in a year is, according to Glaisher, 678,505. Its descent, in due season, in the form of snow and rain upon the land, to qualify it for the support of animal and vegetable life. The water flowing in rivers towards seas, a fair criterion of the amount of evaporation from the surfaces of the latter.

Diffusion of Vapours.

85. *Graham's Law.* Vapours and gases subject to the law, *when brought in contact with each other, they diffuse themselves into each other's masses with a rapidity inversely as the square roots of their densities.*

86. Regnault has carried out the law to mixed gases, and shown that,

I. *The elasticity of the vapours of two liquids in union, which do not mix, is equal to the sum of the elasticities of each of them separately; but if they do mix, it is less than that sum.*

II. *The elasticity of the vapour of water in the air is equal to what it is in vacuo.*

87. Experimental method by which Professor Graham established the law just enunciated. Carbonic acid gas, one of the most noxious of gases, generated profusely by organic processes, and combustion of wood and coal, rendered harmless by virtue of this law. The importance of the law in the economy of nature, in prevention or rectification of noxious exhalations generally. Solids and liquids converted into gases at temperatures special to themselves individually. The following are a few:

Ether..........	98°	Sulphur	570°
Alcohol........	176°	Linseed Oil	600°
Water.........	212°	Mercury	660°

Limit, where the gaseous condition of several bodies begins. Evaporation goes on much more actively in a dry than in a moist atmosphere, during the prevalence of wind than during a calm, Ice vapourises, even as water does. The line of perpetual snow, on the southern aspect of the Himalayas, lower than on the northern on this account.

88. The pressure of the atmosphere controls and keeps down evaporation. The vapour of water would constitute an atmosphere, did it not already exist, through conversion of part of the liquid itself into gas. If the moon have not an atmosphere, she cannot have free liquid about her.

Experiment.

A few drops of æther introduced into the Torricellian vacuum of a barometer tube. The æther flashes into gas, projecting the mercurial column downwards, and continuing to occupy its place in the gaseous form.

89. Gas becomes vapour when the generating fluid in contact with it is cooled down below a certain temperature—in the case of water, and with a barometric column of 29·8 inches, below 212° F. Particles of vapour consist of exquisitely fine bladders or tubes. The diameter of the largest of these found to be $\frac{1}{2780}$ of an inch, and smallest $\frac{1}{4500}$. If condensation take place on a cold surface, the gas is at once changed into water. Instance of this seen in the condensation of a jet of gas on the outside of a vessel containing artificially cooled water.

Experiment.

Condensation effected on the surface of a flask in which sal-ammoniac is being dissolved.

90. One cubic inch of water convertible into 1694 cubic inches of steam.

91. A drop of water, put into a strongly heated cup, does not resolve itself into vapour at once, but continues rolling about, for a time which is proportioned to the heat of the cup. The drop, while slowly dissipating, retains its shape and assumes a gem-like brilliancy. Water in this state called "Spheroidal Water."

Experiment.

A drop of water is allowed to fall into a platinum cup, placed over a spirit lamp, The drop rolls about, gradually and slowly dissipating.

92. *Table of the boiling point of water, indicated under different atmospheric pressures.*

Barometer shows.	Water boils.
27·7	208°
28·29	209°
28·84	210°
29·41	211°
29·8	212°
30·6	213°

93. A rise or fall of the barometric column of 0·1 inches, raises or lowers the boiling point 0·176° on Fahrenheit's scale. Cause of this variation considered. Applicability of this law to the ascertainment of heights. For every 530 feet of perpendicular height, water boils at one degree of Fahrenheit less. Found by De Saussure to boil, at the top of Mount Blanc, at about 187°.

Experiment.

A vessel, containing heated water, has the pressure of the air gradually withdrawn from it. The water again boils, although the temperature be, as shown by a thermometer immersed in it, much below the boiling point.

94. As in the air, so have different liquids different boiling points in vacuo; for instance:

Ether boils under such circumstances at			38° F.
Alcohol	„	„	49° „
Water	„	„	88° „

95. Property of fluids, of boiling under diminished pressure, availed of in the refinement of sugar, making of perfumes and of several medicines. Description of the method used in the refinement of sugar. Reason of the superiority of perfumes so manufactured, to those prepared by ordinary distillation, pointed out.

96. Steam, apart from the producing fluid, possesses no elasticity. The vapour of water expands from the freezing to the boiling point ·002036 of its volume for every degree of heat. This number, therefore, the co-efficient of expansion between these limits. Increase of elastic force with increase of temperature. The table of elasticities prepared by the French Academy exhibited and discussed.

Abstract from the Table of the French Academy.

Elasticity of Steam, Atmospheric Pressure being unity.	Temperature of Fahrenheit.	Elasticity of Steam, Atmospheric Pressure being unity.	Temperature of Fahrenheit.
1	212·00	10	358·88
2	250·52	12	374·00
3	275·18	15	392·86
4	293·92	20	418·46
5	307·50	25	439·34
6	320·36	40	486·59
8	341·78	50	510·20

97. Marcet's boiler.

EXPERIMENT.

A strong spherical boiler is fitted with a graduated tube, 30 inches long and open at both ends, reaching to the bottom; as also with a thermometer, penetrating

through the upper wall merely. Mercury is introduced into the boiler, so as to cover to a small depth the orifice of the tube, and above this a little water: heat is now applied and the water boils, the imprisoned steam forcing the mercury up the tube to a height increasing rapidly with increase of temperature,—the purpose of the thermometer is to indicate this temperature.

98. Steam at high pressure does not scald as low pressure steam does, its sensible heat being employed in rapid and violent expansion, apparently.

CHAPTER VII.

HYDRAULICS.

99. Nature and scope of the subject.

The construction and action of Pumps.

100. Practical importance of the subject. The use of pumps in raising water, from permanent sources in the earth, for irrigation, or for domestic uses. For elevating it to the upper portions of high buildings. For projecting it against fire, or in prevention thereof, in conflagrations.

101. Pumps divisible into two great classes, *Sucking Pumps* and *Lifting Pumps.* The former class of pumps derive their name from their construction, whereby water is raised by means of exhausted tubes. The name in the first instance probably suggested by the withdrawal by the lips, or sucking, of air from a tube, the free end being immersed in water. Indefinite notions generally entertained, regarding the cause of the ascent of water, in such cases. Its true explanation due to Torricelli, the Florentine Professor already mentioned. His deduction from the fact, that water would not rise in pumps when the vacuum exceeded 32 to 35 feet. Crucial demonstration of Torricelli's theory by Pascal.

Experiments.

First.—A tube, one end resting in a vessel containing water, has an air-tight piston fitted into it. The piston being raised, the atmosphere acting on the water, the water follows it.

Second.—The atmosphere is withdrawn from the surface of the vessel by means of the air-pump. The piston is now raised, but the atmosphere not acting on the water, the water does not follow.

Third.—A working model of a sucking pump used instead of the tube, with the same results.

Fourth.—The fountain experiment.

102. *Sucking Pumps.*—Their construction and mode of action described and illustrated by experiment. Difficulty of keeping such pumps in working order, through shrinking of the piston, valves, &c. This difficulty would be enhanced in these parts, even where water might be within reach. Feeding of the pump, as it is technically called, in what consists.

103. *Lifting Pumps.*—The construction and mode of action of this class of pumps described and illustrated by experiment. This species of pump, when supplied with an auxiliary tube and valve, capable of raising water to any height, provided the material of which it is composed be strong enough. The requisite strength, at different points in the tube, is as the height above them to which the water is to be raised. The strain to the piston rod is, in this case, in the direction of its greatest strength. Modification of the pump last described, which constitutes the *Forcing Pump.* In this modification the water is thrust up the auxiliary tube by a pushing force, instead of by a lifting one. Strain to which the piston rod is subject in this case. Capabilities of this pump. The strength of the tubes an important consideration in this case also. This form of pump, with arrangements suitable for the purposes of its application, constitutes the fire engine.

104. Reconsideration of the limits of working in pumps. The height of the barometic column varies, ordinarily, from 30 to 28 inches. The column of water and that of mercury are equally

measures of atmospheric weight. They must therefore both vary directly as that weight, and in amounts proportioned inversely to their respective densities. The density of mercury is 13·6 times that of water nearly. Hence 30 inches of mercury equals 34 feet of water, and 28 inches of mercury 31·7 feet. For the pump to work when the barometer shows 28 inches, the length of vacuum must obviously not exceed 31·7 feet. This is the limit beyond which the vacuum should not extend. For the minimum strength of auxiliary tubes, we have the formula

$$P = \frac{15}{31 \cdot 7} \times h$$

where P is the pressure on the square inch in lbs., h the perpendicular height through which the water has to be raised, above the point for which P is taken.

Other Machines for Raising Water.

105. *The Hydraulic Belt.*—In this contrivance water is raised by causing a belt of cloth, or other substance, to revolve rapidly through the fluid which is to be raised. The water rises by adhesion to the surface of the belt, aided by constant propulsion upwards, the surface should, therefore, be rough.

106. *The Persian Wheel.*—Water raised by this contrivance by buckets or other vessels, fixedly arranged round the periphery of a wheel and made to revolve with it; they fill themselves in succession at the bottom, and empty out their contents as they arrive at the top. Circumstances for which they are suitable. Extensively used in Egypt.

107. *The Lever and Bucket.*—This mode of raising water much used in India and in the Islands of the Eastern Archipelago, being suited for the raising of water through small heights.

108. *The Screw of Archimedes.*—This contrivance of little practical value. Curious from its construction, by which water is made to rise upwards by running downwards.

109. Pressure of the liquid itself, availed of for the raising of water, instead of such means as the above. This the case in Artesian Wells. That of Grenelle produces about 740,000 gallons a day, from a depth of about 1800 feet. Such wells may be sunk wherever a stratum, capable of retaining water, slopes or bends downwards to a cup-like form. The Paris and London basins furnish these conditions—the water being contained between beds of clay, as if between two cups placed one within the other.

110.—*The Syphon and its principle of action.*—The Syphon, unlike the machines just described, is not suited to the transfer of fluids to a higher level, but to a lower one. Let the Syphon be filled with fluid, and the shorter limb immersed in the fluid to be transferred. If P be the pressure of the atmosphere, p the pressure due to the fluid in the limb immersed, p' the pressure due to the fluid in the discharging limb, we have the condition of action of the Syphon.

$$P - p > P - p'$$

The pressures p, p' are as the heights of the columns; hence the Syphon must have a shorter limb for raising the fluid than for discharging it; otherwise, the orifice of the discharging limb must be at a level below that of the surface of the fluid to be transferred.*

111. *Tantalus' Cup.*—Description of and experiment therewith.

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* Appendix, Note K.

Discharge of Liquids through Orifices.

112. The discharge of a liquid, through a conically shaped orifice in the bottom of a vessel, is found to be such as it would acquire by falling freely through a space, equal to the depth of the liquid. The same velocity attends a discharge by a lateral opening, close to the bottom.*

Ajutages.

113.—Lateral openings in the side of a cylindrical vessel, if of the same capacity, will discharge, in the same time, quantities proportioned to the velocities. The above law is therefore demonstrable, proximately, by experiment. The jets describe curves; the greater curvature of the jets, according to higher situation, indicates diminution of pressure with diminution of depth. The curves found to be parabolic.†

114. *Fountains.*—Natural Fountains, Fountains of Compression, Hiero's Fountain.

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* Appendix, Note L. † Appendix, Note M.

CHAPTER VIII.

STEAM: ITS POWERS AND ITS APPLICATION.

115. Any amount of power obtainable through the agency of steam. Such power available as a moving force. Steam of 250°, *i.e.* 38° above the boiling point, exerts, as already seen, a force of 30 lbs. on every square inch. Rapid increase of force with increase of temperature, as seen in the following Table.

Temperature F. above 212°.	Pressure per square inch in lbs.
38°·52	30
63°·18	45
81°·72	60
95°·5	75
108°·36	90
119°·7	105

116. Spheroidal water found to throw off steam of high tension, mixed perhaps with the constituent gases of water. This steam applied, by way of experiment, to the propulsion of machinery. No practical use of any moment has as yet been made of it.

The Steam Engine.

117. The elementary form of the condensing apparatus.

Experiment.

A glass tube blown into a bulb, at its sealed end, has a piston fitted into it. Water is introduced into the bulb below the piston and brought to boil. The steam thus produced raises the piston. The bulb is now plunged into cold water; the steam is by this means condensed, and thus a vacuum left under the piston, which the atmosphere now thrusts down to the bottom of the tube.

118. The method of condensation adopted in the above experiments inconvenient in practice. Method of condensation by injection. Disadvantages of this method. The remedy invented by Watt, the deviser of the above experiment, and justly styled *the father of the Steam Engine*, viz., the condensing of the steam in a vessel apart from the working cylinder. Limit of power in engines made on the rudimental principle. Remedy for this also invented by Watt, viz., in working the piston by steam introduced at both ends of the stroke. High and low pressure steam engines what, and why so called.

119. Description, and demonstration by means of diagrams and models, of the steam boiler. Consequences which would result from sudden change of level in the water. Means by which a constant level of the water in the boiler is preserved. Artifice by which uniformity of elasticity is maintained in the steam.

Application of Steam as a Moving Power.

120. Way in which this power is made to act on machinery generally. Its adaptation as a propelling agent. Demonstrations, by means of models.

First.—As applied to Ships.

Second.—As applied to Locomotives.

121. A working model of a locomotive, with its train of carriages, exhibited and described. Security and speed of travelling by aid of steam, in comparison of that by ordinary means, considered. Incalculable benefit, present and prospective, to mankind, resulting from the discovery and application of the power of steam.

Application of Steam to Domestic Uses.

122. The method of applying steam to culinary purposes and to the warming of buildings, &c. described.

CHAPTER IX.

THE ATMOSPHERE.

123. The interest attaching to the study of the atmosphere, as being the reservoir of oxygen, that essential to the life of man and animals,—of carbon an indispensible aliment of plants; for its beneficial effects on light, and the like. Many of its properties familiar and well understood. Many phenomena occurring in it yet imperfectly explained. Atmospheric air to be adopted as a type of the gases generally. Discrimination between *general* and *special* qualities to be observed; for instance, its fluid nature amongst the former, its weight among the latter.

124. The atmosphere made up of three gases, with a trace of a fourth, viz.

Oxygen	·21
Nitrogen	·785
Carbonic acid	·005
Ammoniacal gas, a trace..........	
Total........	1·000

General Properties of the Atmosphere.

125. *Impenetrability.*—Manifest from the resistance it offers to being compressed beyond certain limits. Liquid condition of most gases suggests the same property. This condition common to all forms of matter under certain circumstances. Obvious identity of

mechanical properties in this state. Identity of essential properties also inferred. Marriott's law leads to the same conclusion.

126. *Divisibility*—proved by its lurking in the pores of liquids; expansion and thinning out in the receiver of the air-pump, &c.

127. *Extension*—too obvious to require proof.

128. *Inertia*—made sensible to us whenever we move rapidly. The motion of ships, and boats propelled by sails, due to the same property.

129. *Weight, suspected* by the ancients before Aristotle; *proved* by Galileo.—The absolute as well as relative weights of the atmosphere, and of gases generally, may be accurately ascertained. 100 cubic inches of air at the sea level weighs 30·5 grs., about $\frac{1}{841}$ part of the weight of as much water: its specific gravity therefore, at standard pressure and temperature, ·0012 nearly.*

130. The air pump described, and its mode of action explained and demonstrated.

Experiments.

First.—A bladder secured upon one end of a glass cylinder has the air withdrawn from under it. The pressure of the air ruptures it, and thrusts it inwards with violence.

Second.—A hollow sphere of copper, fitted with an air-tight stop-cock, is weighed when full of air. It is then exhausted and again weighed; it is now found to have lost in weight nearly twenty grains, about the amount calculated for its capacity, the same by inverting the order of the experiment.

131. *Elasticity.*—Elasticity particularly conspicuous in gases. Carbonic acid gas, when permitted to escape from the liquid state,

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* 252·5 Weight of 1 cubic inch of water.
25250 „ 100 „

Hence $\frac{30 \cdot 5}{25250} = \cdot 0012$ nearly.

expands with great velocity, freezing itself thereby. The elasticity of gases admits of striking illustration.

EXPERIMENTS.

First.—Semi-flaccid bladders, containing different gases, have the pressure of the air withdrawn from their surfaces;—as relief proceeds, expansion follows.

Second.—A semi-flaccid bladder, under weights, raises them as the receiver becomes exhausted.

Third.—The air-gun. Description of and demonstration therewith.

SPECIAL PROPERTIES OF THE ATMOSPHERE.

132. Identity of the general properties of the atmosphere with those of solid bodies re-adverted to. The special properties of the atmosphere. These due to its bulk, situation, &c. Their deep interest to us, not only as philosophers but as men.

133. The atmosphere compared to an ocean of unknown depth. The great pressure, which terrestrial beings are subject to, rendered insensible through its equal application to all parts of surfaces. Surface of the body of a man of ordinary stature about 15 square feet; hence the pressure to which he is subject about 14 tons, or 292 mds. Divers in diving bells, if gradually lowered, can sustain a pressure of three atmospheres without inconvenience. The harmony of creation thereby manifested and sustained. Amount of atmospheric pressure.

GRAVITATION OF THE ATMOSPHERE.

134. Evidence afforded by pumps. Pascal's experiment by means of a tube, 48 feet long, filled with wine, and raised and lowered by pulleys.

EXPERIMENT.

The Magdeburg hemispheres are exhausted of air;—they resist the exertion of ordinary force to pull them apart.

135. The resistance, in the Magdeburg experiment, proportioned to the exterior surface of the hemispheres. Uncomfortable sensations experienced by man on the tops of high mountains. Gay Lussac ascended to a height of 25,000 feet. He found the barometer sink 17·7 inches, and Fahrenheit's thermometer 10° C below zero. Messrs. Barral and Bixio, about the same season, experienced a cold of 40° C below zero. Improbability of intercommunication between distant places through the air. Attempts described, and their results. The necessity of air to the support of winged flight, finely availed of by Milton in his description of Satan's escape from Hell. The explanation of the ancients, that "nature abhors a vacuum." The failure of that explanation in the cases of mercury and water. These do not ordinarily rise in vacuo above 30 inches, and 34 feet respectively. The Royal Society of London have a water barometer, the length of the tube of which it about 40 feet.

136. Torricelli discovers the true cause of the ascent of fluids in vacuous tubes, viz., the pressure of the atmosphere. He compares the specific gravities of mercury and water, and the heights of their columns in vacuo. He finds the heights to be inversely as the specific gravities. Demonstration by Pascal. The obligation conferred on the scientific world by this discovery.

Experiments.

First.—A tube sealed at one end, and filled with water, remains full if the open end be immersed in water.

Second.—A tube sealed at one end, and filled with mercury, has its open end immersed as in the last case. The fluid descends, until the length of the column equals about 29 inches.

Third.—The vessel in which the tube, containing the mercurial column, is immersed, is introduced into the receiver of the air-pump. The air being removed from off the surface of the mercury, the latter forsakes the tube, depositing itself in the cup.

Fourth.—The air is re-admitted, the mercury rises again to the same height as before.

137. A column of mercury 30 inches high, in a tube whose bore equals one square inch in section, gives (the weight of a cubic inch of mercury being 7·85 ounces) $30 \times 7{\cdot}85 = 14{\cdot}9$ lbs. or 15 lbs. nearly. This, consequently, the pressure of the atmosphere upon every square inch of the earth's surface. The equation for the pressure is $p = dgh$, where d is the density of mercury, h the height of the column, and g the force of gravity. A correction necessary in the formula, where great accuracy is required, on account of the expansion of mercury due to varying temperature. Mercury expands $\frac{1}{9990}$ part of its bulk for 1° of Fahrenheit, and for t^0, $\frac{1}{9990} = 0{\cdot}001001.t$. The equation $p = dgh.\ (1 + 0.001001.t)$, gives the pressures very closely. The vacuum left in the tube, by the descent of the mercury, in the second experiment, called the Toricellian vacuum, after the discoverer of its true nature.

The Barometer.

138. Construction and use of the Barometer described. Barometers of two kinds, with their modifications; one where a straight tube dips into a cup of mercury; the other, where the terminal end of the tube is bent upwards. Demonstration by aid of sectional sketches, and of the instruments themselves. The Aneroid Barometer.

139. The equilibrium would not be disturbed were the shorter limb, of the second kind of barometer, produced as far as the upper limit of the atmosphere. The experiment of mercury and water in a syphon tube repeated in illustration.

140. The descent of mercury, on ascending hills, in the barometer. The diminution serves to show the height above the surface, or level, of the sea. Pascal's experiment. He carries a bladder which was half full of air at the foot of the Puy-de-Dome

to the top, the bladder swells out as he ascends; he brings it down again—it collapses to its former volume. Construction and use of the mountain barometer.

141. The volumes of air are inversely as the densities: the height of the atmosphere, consequently, much greater than it would be on the hypothesis of equal density throughout. Leslie's formula for ascertainment of heights, by comparison of barometric columns.

As the sum of the mercurial columns is to their difference, so is 52·000, *to the elevation of the higher station, above that of the lower one.*

Mass and Height of the Atmosphere.

142. Let S be the surface of the earth in square feet, then

$$M=2{\cdot}5\,d\,S$$

expresses the mass of the atmosphere.*

143. Diurnal oscillation of the barometric column—at the equator—observed by Humboldt.

Phases of Oscillation.	Times of Oscillation.	Length of the Barometer Column.	Movement of the Column.
Relative minimum.	4h. morning.	H — ·0176 in.	Rises.
Absolute maximum.	9h. morning.	H + ·0441 in.	Falls.
Absolute minimum.	4h. evening.	H — ·0353 in.	Rises.
Relative maximum.	10h. at night.	H + ·0088 in.	Falls.
Relative minimum.	4h. morning.	H — ·0176 in.	

H the mean height of the barometer.

Note.—Amplitude in Europe, according to the same authority, of diurnal variation 0·07874.

* Appendix, Note N.

144. Were the atmosphere of the same density throughout, its height and that of the mercurial column would be inversely as their densities. The density of mercury is 11065 times that of ordinary atmospheric air, at the sea level. We have for the height of the atmospheric mass, under these circumstances

$$h = 11065 \times 2{\cdot}5 \text{ feet}$$
$$= 5 \text{ miles nearly.}$$

Modifications to this result proved by experience to be necessary.

145. Decrease of density, therefore of pressure, with increase of aqueous vapour. Gay Lussac found the density of the vapour of water to that of dry air to be as 10 to 16 nearly. The use of the barometer as a weather glass, greatly dependent upon this fact.

146. Decrease in density with increase of altitude. As the height increases in arithmetical progression, the atmospheric volumes increase in geometrical progression. Table of relation of atmospheric height or density.

Height above the sea in miles.	Volumes.	Pressure.
0·000	1	30 in.
2·705	2	15
5·410	4	7·5
8·115	8	3·75
10·820	16	1·875

147. Probability that the height of the atmosphere does not exceed 45 miles, considered. Limit not beyond the height, where the centripetal and centrifugal forces balance each other. Consequences of its exceeding this limit. The wisdom of the deity manifest in the assignment of such a limit.*

* Appendix, Note O.

Balloons.

148. Their construction, and use in Ærostation, described. Heads of discussion.

First. Condition of Ascent.

Second. Limit of Ascent.

Third. Method of Descent.

Fourth. Method of Re-ascent.

The Trade Winds.

149. The Direction of the Trade Winds constant from N. E. and S. E. on the north and south sides, respectively, of the Equator. Their importance to navigation. The Trade Winds seem chiefly due to the excitation of the intertropical regions, by the sun's rays. Prevailing winds at Agra, and Monsoons in Bengal, to what causes due.

150. The influence of the Trade Winds in equalizing temperature. The occasion afforded by them to general intercourse amongst men. The provision they afford for harmony, and equilibrium in the organic world.

151. The atmosphere considered as a vehicle of Sound. Its perfect compatibility with this office. The wants, sympathies, and thoughts of men and animals, thus readily communicated to one another.

152. Sound propagated in all directions from an excited sonorous body. Rate at which it travels, in ordinary conditions of the atmosphere, 1130 feet per second.* The distance of dis-

* The authorities quoted by Herschel give the velocity at the freezing point, and under ordinary pressure, about 1122 for ordinary temperatures. These determinations are for the sea level; at higher elevations the elasticity becomes enhanced and therefore the velocity greater, as also because the mass to be moved by the wave producing power is less.

charged artillery, or of a thunder-cloud, may be thus determined. The atmosphere not the best conductor of sound. Biot's experiment, in proof of this, described. Experiments carefully performed, under water, have shown its conducting power to be about 4708 feet in a second.

153. Without an atmosphere sound could not exist.

EXPERIMENT.

A Bell is fixed in the receiver of an air-pump, and the air exhausted; the bell when agitated gives no sound.

Discussion of the experiment.

154. Whirl-winds: their origin and motion. Cyclones.

CHAPTER X.

HEAT.

155. Sources of Heat. The chief natural sources of heat, the sun and thermic springs in the interior of the earth: the former produces temperature; the latter begets volcanic and other forces, and is an essential condition of the production, and continuance, of animal and vegetable life.

156. Universal presence of heat. Faraday succeeded by artificial means in reducing heat to—166° of Fahrenheit; and M. Natterer produced cold of—240° F. by mixing together nitrous oxide and sulphuret of carbon in vacuo. The expressions *hot* and *cold*, of comparative signification only. No ground for believing that either extremity of the scale has yet been arrived at. Galvanic heat, which burns the most refractory metals, not to be assumed the most intense possible. Recent theory of Professor Grove, that heat and motion are only different manifestations of the same power. Professor Thompson supports the same view mathematically. Undulatory and radial theories. The former makes heat analogous to light and sound.

157. Caloric classed among imponderable bodies; is capable of being absorbed and treasured up in great quantities. No difference of weight resulting from such saturation.

158. Remarkable power of endurance of heat in human beings. A young woman remained for some time in an oven heated to 262° of Fahrenheit. A Frenchman gained a livelihood, a few

years back, by exhibitions in this way: such as carrying victuals into a heated oven; waiting till they were cooked, and bringing them out again. Suitableness of this quality to the destiny of man.

Evaporation.

159. Cooling effects of Evaporation. From the skins of men and animals. From the ground. The accumulation of heat in the surface of the earth, in the N. W. Provinces, before the setting in of the rains. This heat, imparted to the air, causes the winds called "hot winds." On the falling of rain, evaporation commences, and heat becomes thereby absorbed. Hence the coolness which attends the setting in of the rains, and which is experienced also when, upon an east, moisture-bearing, wind, the dry west wind sets in, causing sudden rarifaction in the atmosphere. Astonishing proof of the cooling effect of evaporation, devised by Boutigny. He froze water in a muffle, alongside of gold and silver in fusion, by means of sulphurous acid. A punkah does not reduce temperature: it changes the air in contact with the skin only, thus promoting evaporation. Dogs dislike punkahs.

Experiment.

First. Cooling effect of evaporation shown, by pouring heated water, from the same kettle, into two bolt-heads; the one being made to boil under the receiver of the air-pump, the other allowed to stand apart. That which has been boiling is found to be of lower temperature than the other.

Second. The bulb of a thermometer, enveloped in muslin rag, has æther dropped upon it, the mercury in the tube descends.

Three States of a Body.

160. Bodies have three states common to them, in relation of heat.

First. By heat, they become gases at a point called the "Boiling point."

Second. By cold, they become solids at a point called the "Freezing point."

Third. Between the freezing and boiling point they are liquids.

The Corpuscular Theory of Laplace.

161. The three states of a body, viz: *Solid, Liquid, Gaseous,* depend, according to Laplace, respectively upon—

The absence of heat between the constituent particles.

The presence of heat of but little force.

The presence of heat of sufficient force to dissipate the particles.

162. Expansion of fluids by increase of heat, and solidification by cold. This augmentation, and diminution, employed for ascertainment of temperature. Of fluids, quicksilver best adapted for this purpose, on acconnt of the evenness of its expansion, within the limits of its own freezing point and the boiling point of water, at a rate given in para. 137, page 49.* Its indications also true beyond the latter point. Alcohol—spirit of wine—preferable for very low temperatures.†

The Thermometer.

163. The mode of construction, the graduation, and the principle of action of the Thermometer, described.

Thermometric Scales.

164. Three kind of Scales in use; those of Fahrenheit, Reaumur and Celsius—the latter known also by the name of the

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* Regnault's formula of expansion is

$$1 + 0{\cdot}000179007\,t + 0{\cdot}0000000252316\,t^2$$

the scale for t being centigrade, and the unit taken at 0 of that scale.

† Appendix, Note P.

Centigrade Scale. Comparative view of their graduations shown. Origin of the zero point in Fahrenheit's Thermometer. Equations for converting any degree, of one of these scales, into an equivalent degree of another.

$$180F^{*}=100\,C=80\,R$$

$$\therefore F = \frac{5}{9}C = \frac{4}{9}R$$

$$C = \frac{9}{5}F = \frac{4}{5}R$$

$$R = \frac{9}{4}F = \frac{5}{4}C$$

General equation of conversion.

$$x^{\circ}\,F=(x-32)^{\circ}\frac{5}{9}\,C=(x-32)^{\circ}.\frac{4}{9}\,R$$

165. All bodies, solids as well as fluids, expand by heat. Importance of this fact to the arts. The tires fixed on the wheels of carriages by virtue of this principle. The tire is made a little too small at first, then heated and applied to the wheel; when cool, it contracts and binds the wheel tightly. A very striking application of the same principle made in Paris. The walls of the Museum of Arts and Manufactures had bulged out; strong iron bars were passed through the walls near the roof, the protruding ends bearing iron disks, which could be screwed towards each other. Alternate bars were heated, and thus lengthened; the disks were now screwed up close to the walls and the bars permitted to cool. The contraction which followed, in the bars, drew the walls towards each other. The same process was repeated on the other bars; and so on, until the walls were restored to the perpendicular.

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* $212^{\circ}-32^{\circ}=180^{\circ}$ the distance in degrees between the freezing and boiling points of water, in Fahrenheit's scale.

166. Water expands above 40° F by increase of temperature, and below the same temperature it expands by increase of cold. Hand of Providence visible in this law.

167. A simple experiment, to illustrate the expansion of metals by heat, performed. A bar of metal, fitting when cold into a metallic groove, does not do so when heated. Metals expand differently by the application of heat. Platina expands the least, and lead the most. If a rod, consisting of two slips of different metals soldered together, be heated, the rod becomes incurvate, by unequal expansion of its constituent metals.

168. A compound bar of copper and iron, made in the cold climate of England, and intended for illustration of different expansibility, exhibited. It is permanently incurvated by the high temperature of India. Importance of this fact considered, and the remembrance of it enjoined. Were an iron tube for the transmission of steam, or of boiling water, or even a bar, subject to great variation of temperature, to abut against a building; the building, on the tube or bar being heated, would be thrown down, or they would themselves break. Bars of different metals may be so associated, that the change in length, under varying temperature, shall be neutralised. This done in Chronometers, Pendulums for Clocks, Rods for Geodesic purposes, &c. Compensations, construction of Pendulums, and Balance-Wheels.

The Pyrometer.

169. The Pyrometer, an instrument for measuring the expansion of metallic bars by heat, and conversely. The instrument exhibited, and the principles of its construction described. Experiments with bars of different metals illustrative of its use.

Table showing the amount of linear expansion of a few solids, on heating them from the freezing point of water to the boiling point of the same.

Lead	1 on 351	Brass	1 on 584
Glass	1 „ 491	Pure gold	1 „ 682
Silver	1 „ 524	Iron wire	1 „ 812
Copper............	1 „ 581	Platinum	1 „1167

170. *Expansion in volume of a few fluids within the same limits.*

Air......................	30	measures	become......	31
Alcohol	9	„	„	10
Fixed oils	12	„	„	13
Water	22·76	„	„	23·76
Mercury..................	55·5	„	„	56·5

171. The co-efficient for the total expansion by heat, three times that for the linear expansion.*

Incandescence.

172. All bodies, solid or fluid, become incandescent at the same temperature, viz. about 977° of Fahrenheit's scale.

Latent Heat.

173. The subject of latent heat resumed. Familiar instances and examples. Modes of production in nature and art. By solution. By vaporization. Advantages to domestic comfort, resulting from an acquaintance with its nature. Evidence in the effects of evaporation already noticed.

* Appendix, Note Q.

174. Numerous means adopted for the production of intense cold, according to the purpose to be subserved by it. A body changed from the solid to the fluid state, renders latent a great deal of heat. Ice exposed to a warm atmosphere dissolves; the atmosphere becomes cool in the vicinity, while the solution is proceeding; the fluid having no higher temperature than that of the ice, so long as any portion of the ice remains undissolved. 1 lb. of water at 172°, mixed with 1 lb. of ice at 32° gives the product 2 lb. of water at 32°. Here 140° of heat has been rendered latent by the solution of the ice.*

175. An efficient mixture for the cooling of water, or of wines, made by the taking 5 parts of sal ammoniac (Noshadar), 5 parts of nitre, (Shoru), and 16 of water. The water may afterwards be evaporated off, and the mixture preserved. The same material may with care be made to serve several times; but it becomes mixed with other salts from the water, which ultimately impair its efficiency. A cooling mixture, of great intensity, obtained by dissolving finely pounded sulphate of soda in muriatic acid.

Experiments.

First. Water cooled by a mixture of sal ammoniac, nitre, and water.

Second. By solution of sulphate of soda in muriatic acid.

176. Bodies passing from the solid to the liquid, as also from the liquid to the gaseous state, absorb heat. The latter fact how availed of in the arts. The making of ice, in this country, dependent upon it as a prime condition. Water is exposed to the evaporating power of the atmosphere, in shallow earthen vessels. Layers of straw are placed under them, to prevent communication of heat from the earth. The atmosphere being usually very dry

* Heat of the constituents............................ 172 + 32° = 204°
   „   „ product.................................. 32° × 2 = 64°
      Heat rendered latent.................................. 140°

in the cold season, evaporation goes on actively during the night, and consequently absorption of heat; whereby, ere morning, the water is frozen. When the atmosphere is cloudy, and consequently evaporation sluggish, the manufacture ordinarily fails. Description of Leslie's arrangement, for the making of ice under an exhausted receiver, and experiments therewith. A delicate thermometer, placed in the receiver of an air-pump, falls as the exhaustion proceeds.

Experiments.

First. The bulb of a thermometer is covered with muslin rag, and æther dropped upon it; as evaporation proceeds the thermometer falls.

Second. Water frozen by Wollaston's Cryophorus. The empty bulb of the instrument is placed in a mixture of finely pounded ice and salt; the rapid evaporation produced thereby, in the other bulb, causes the water there to freeze.

Daniell's Hygrometer.

177. The Hygrometer, an instrument for measuring the amount of saturation, by moisture, of the atmosphere. Ingenuity and elegance of the instrument devised by Professor Daniell, for this purpose. Production of dew by the Hygrometer, shown by experiment, and practical inferences deduced from the same.*

178. Bodies, in passing from the gaseous to the liquid, and from the liquid to the solid state, give out heat. Effects of motion in producing solidity in fluids. Still water may be cooled down, considerably below the freezing point, without becoming solid. The moment it is agitated it becomes solid and rises to 32°. Water poured upon quicklime forms a solid; during the change heat is given out, so as sometimes to cause ignition.

Experiment.

Spirit of wine is poured into a saturated solution of sulphate of potash, the salt is precipitated, and the temperature of the mixture rises.

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* See Regnault, on Hygrometry Comptes Rendues, No. 26 of 1852.

Distillation.

179. A model of the common Still exhibited and described, while the process of distillation is going on. During the course of ebullition, when once the water has attained the boiling point, its temperature rises no higher, be the fire ever so strong. Increase of temperature of the condensing water caused by the latent heat given out by the steam on condensation, pointed out. Vapour here carries the heat, taking it from the fire and giving it to the condensing water. In culinary processes, it is a waste of fuel to use more than is necessary to sustain ebullition. Liebig's condenser.

Conduction of Heat.

180. Heat, unlike other properties of matter, possesses a tendency to equilibrium. Two differently heated bodies, placed in contact, communicate heat to each other until both of them are equally heated. Existence of heat, as an independent element, argued for on these grounds. The action of the thermometer depends upon this property of heat. Experiments illustrative of this. Some substances become heated sooner than others, when placed in contact with bodies hotter than themselves. Bodies on this account are said to be good or bad conducters of heat. Denser and heavier bodies, generally, conduct heat better than those that are less so. No body absolutely a non-conducter of heat. Liquids conduct slowly. Water may be boiled at the upper part of a test tube, while ice remains undissolved at the bottom.

The following Table exhibits the comparative conducting powers of a few substances.

Gold	1000	Tin	304
Silver	973	Lead	180
Copper	898	Marble	24
Platinum	381	Porcelain	12
Iron	374	Clay	11
Zinc	363		

181. Very low conducting power of clay remarked upon. The wisdom of the Creator manifested, in thus providing for the protection of the vegetable kingdom, against violent changes of temperature, by making the soil a bad conductor. The natural clothing of warm-blooded animals are among the worst conductors of heat, such are hair, wool, feathers, &c. Bears at the north pole, invested with a coating of such material, are protected against the influences of perpetual winter. Wool, used for the manufacture of clothing, in cold climates, on this account. Wrappers made of wool employed, on the same grounds, in this country, for the conveyance of ice from the pits were it is stored. Ice may be preserved for a considerable time, wrapt up in blankets; care being taken that they be dry when used. The husks of cereals, being the clothing of the grain, answer a similar purpose, guarding it against injurious change of temperature.

Experiment.

Several equal slips of different metals have a portion of phosphorus placed on one end. A lighted spirit lamp is introduced beneath the free ends of the metallic slips; the phosphorus on the best conductor ignites first, and so on.

Radiant Heat.

182. Heat considered as emanating from the surface of bodies, and traversing space in straight lines. Such heat technically called radiant. The sun, the greatest radiating body known to us. The temperature of the earth increases as the depth, about 1° for every 60 feet, as appears by its rise downward in Artesian wells. The water of the well of Grenelle issues at a constant temperature of 81° F.

183. Heat from the sun is diffused through space, in intensity, inversely as the square of the distance from him. Probability that solar heat is diminishing. Probable change in organised

forms, on the planets of our system, suited to that decrease. The remains of the elephant, rhinoceros, palms, &c. in cold climates, may be regarded as evidences of this decrease. Lyall's opinion that dry land accumulated about the equator, during the period of the existence of tropical fauna in high latitudes, conducted heat necessary to their being. Poisson's theory, that the temperature of that portion of space through which the solar system now travels is different from that in which it was formerly travelling—it being now in a cooler region than before—unconvincing. The most probable theory, perhaps, is that the sun's heat is on the decrease.* Impossible for us to know whether total organic annihilation will follow, after all his heat shall have become exhausted; or whether there may not exist a power of restitution, without creative interference; if not, whether creative interference may not take place.

184. All bodies, like the sun, emit heat in all directions, and with a velocity proportioned to the relative condition of the bodies. If, in a system of bodies, the temperature of any one body be lowered below that of another, it will soon be restored by radiation from its neighbour. The destruction of organic life would be a consequence of the constant radiation of heat, were there not as constant a supply provided for its replacement. Diminution of temperature on ascending high into the air readverted to. Temperature of space, according to Pouillet, — 255° F.

Experiment.

The bulb of a thermometer, wrapt in fibres of cotton, is placed in the focus of a parabolic mirror, and the mirror interposed between it and the earth. The thermometer, being exposed to a clear sky, falls.

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* The author of the lectures, sketched in this work, has lately met with the same theory, similarly worked out, by Sir John Herschel. Note to 2nd Edition.

185. Dr. Wells' theory of the formation of dew upon the same principle. Melloni and Pouillet verify the theory by direct and varied experiment. Freezing of water upon the leaves of plants, often witnessed in this country, an admirable illustration of this fact. During a cloudy or stormy night, the balance of temperature being then readily restored, dews do not form.

EXPERIMENTS.

First. Two parabolic metallic mirrors, with highly polished surfaces, are placed opposite to, and at a distance from each other; a mass of heated iron is placed in the focus of the one, a delicate thermometer in that of the other—the thermometer instantly rises.

Second. The same arrangement, but with a freezing mixture—the thermometer falls.

186. The first of these experiments shows that heat may be deflected from the surface of one parabolic mirror into the focus of another, placed opposite to it; the second that heat may be withdrawn from the focus of the mirror under similar arrangement. Cold has no positive existence; the diminution or sensible absence of heat is cold. When restitution of heat is not made, as in the falling of the thermometer in the second experiment, we call it cold. Phenomena developed during the two experiments discussed.

187. Principle on which the two last experiments depends. Rays of heat, emanating from the focus of the one mirror and falling on its surface, are deflected from it, in lines parallel to the common axis of the mirrors, and thus falling on the surface of the other mirror are deflected into its focus. The law in this case, the ordinary physical one, that the angle of incidence of the rays is equal to the angle of reflection. Mathematical demonstration of the law.*

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* Appendix, Note B.

188. The best reflectors are the worst conductors. Bodies differently coloured have different radiating and absorbing powers. Black has the greatest absorbing power, and white the least. Professor Leslie places strips of cloth, of different colours, upon snow exposed to sunshine, the black sinks the deeper; on the white no sensible impression is made. A thermometer, which has its bulb blackened, stands higher than one uncoloured. Any thing to be preserved from the effects of heat should be covered by a light, in preference to a dark, pigment or envelope. White clothing not suitable to cold, but appropriate to hot weather. The latter doubtless the reason why experience has suggested the use of white apparel in India. The advantage in having cooking utensils black below, on the outside, and polished above. For keeping fluids warm the containing vessel should be a bad radiator. Fluids, in such cases, to be preserved in vessels the outer surfaces of which are polished. Professor Leslie's experiment with a hollow tin globe. The time required while the surface was polished, for cooling the hot water contained in it from 35° to 25° Centigrade, was 150 minutes. The same globe, covered with lamp-black, required but 81 minutes to produce the same effect.

RADIATING POWERS.

Lamp black	100	Plumbago	75
Writing paper	98	Tarnished lead	45
Sealing wax	95	Clean lead	19
Crown glass	90	Polished iron	15
China ink	88	Do. tin, gold, silver and copper	12
Red lead	80		

189. The comparative radiating powers of different substances, for instance those given in the table, found by varying the coating of the globe. Lamp-black the best radiator, and polished tin, gold, copper, and silver, the worst. Difference of

radiation between the same metal hammered and cast, when its surface is polished, and when slightly scratched.

Experiments.

First. Cubical vessels of tin are filled with boiling water, and the strength of radiation tested. The heat emitted by the blackened surface found to be the greatest, by the polished one the least, and so on.

Second. Two disks, one blackened, the other polished, are provided with phosphorus bearers. The disks are made to radiate by exposures to equal heat; the phosphorus of that which is blackened becomes ignited, while that of the other remains unchanged.

Specific Heat.

190. Bodies have capacities for heat special to themselves, which is constant for the same body, and which, with reference to some standard, is the measure of the *Specific Heat* of that body.

191. If a cubic inch of iron, on being heated from the freezing to the boiling point of water, absorb a certain quantity of heat, the same mass of iron, in the same condition, will always absorb the same quantity of heat; a cubic inch of lead will, however, absorb a different quantity of heat, under the same condition, and so for other substances. The quantities of heat taken up by the iron and lead respectively are their specific heat.

192. In most bodies the effect produced by a given amount of heat differs, for different temperatures of the bodies. In the case of water the effects are equable. Water taken, therefore, as the standard of specific heat.

193. The specific heat of bodies will under the same thermal conditions vary inversely as the effect produced on their masses. If c, c'; m, m'; t°, t'° be the specific heats, masses, and tem-

peratures produced by the same quantity of heat, of two different bodies; we shall have—

$$\frac{c'}{c}=\frac{m\ t^{\circ}}{m'\ t'^{\circ}}$$

If c be the specific heat of the standard body, and therefore unity, we have—

$$c'=\frac{m\ t^{\circ}}{m'\ t'^{\circ}}$$

If the masses be equal, i.e. if $m=m'$

$$c'=\frac{t^{\circ}}{t'^{\circ}}$$

194. The *Specific Heat* of bodies determined by several methods. The following is the most convenient:

First. By heating them from a known temperature to to the boiling point of water, and then observing the thermometric effect produced by cooling them in a given quantity of water.

Second. By observing the time which they require to cool down to a given temperatnre, in a closed and polished silver vessel.

195. Dulong's Law: *The Specific Heat of bodies is inversely as their atomic weights.*

Cor. The atoms of simple bodies have the same capacities for heat.

Detailed Experiment.

196. Determination of the specific heat of brass by the first method:—

Weight of brass	1000 grs.	
Do. water 4 oz.	1920 ,,	
Brass heated to	212°	Fahrenheit.
Temperature of water prior to experiment ...	69°	,,
Do. Do. after Do. ...	76°	,,
The 1920 grs. water have thus been heated by the cooling of 1000 grs. of brass	7·00	,,
Consequently 1000 grs. would have been heated 1·92 × 7°.................................	13·44°	,,
Again, 1000 grs. of brass have been cooled down (212°—76°) 136° in order to heat 1000 grs. of water................................	13·44°	,,

The capacities of the two substances for heat are therefore 13·44: 136. Hence, taking water as the unit, the specific heat of brass is, by the equation given above—

$$\frac{13{\cdot}44}{136} = {\cdot}099$$

CHAPTER XI.

ELECTRICITY.

197. Electricity, a power known to be inherent in amber by Thales, 600 years before the Christian era. The same knowledge possessed by the Arabs also, probably derived from the Greeks. Amber called in Persian, Kyroba, "the straw-attractor." Specimens exhibited, and its characteristic property shown.

198. Universal prevalence and dominion of electricity. Great interest attaching to the subject. Discoveries of Professor Faraday. Their scientific and economic value. Identity of the directing power of the magnet and the thunderbolt. Light found to be subject to electric influence, and may be made to revolve thereby similarly, to a metallic needle. Electricity revealed to our senses only when its equilibrium is disturbed. Like heat, electricity does not augment the weight of bodies. Its essential nature yet unknown. Its physical properties the subject of our discussion.

199. Franklin's view, that there exists but one kind of electricity, through in different intensities. Excess termed by him *positive;* defect, *negative* electricity. General opinion at present in favor of two forces or fluids, possessing common and distinct properties; sometimes termed vitrious or resinous, as they are of the kind excited by friction on glass or on resin, respectively. The terms adopted by Franklin more frequently used. The subject naturally divides into two distinct branches; Frictional

Electricity, and Galvanic Electricity. Frictional Electricity the subject of the present chapter.

FRICTIONAL ELECTRICITY.

200. Many substancs, such as amber, glass, shell-lac, &c., when subjected to friction, develope electricity; hence the name adopted for this division of the subject. A dry atmosphere necessary to success in such experiments.

EXPERIMENTS.

First. A feather, suspended by a fibre of silk, is attracted by an excited glass rod, and is then repelled by it.

Second. The same with a rod of lac.

Third. Balls of pith, fragments of paper, &c., are alternately attracted and repelled by either rod.

Fourth. The feather, repelled by the glass rod, is attracted by the lac one, and reciprocally.

Fifth. Feathers, excited by either rod, repel each other.*

LAW.

Like kinds of electricity repel, and unlike kinds attract each other.

THE GOLD-LEAF ELECTROSCOPE.

201. The instrument exhibited; and the principal of its construction, and of its action, described. Its efficiency, as an indicator, also as a measurer of free electricity, considered. Temporary and prolonged separation of the leaves.

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* The feathers of the peacock's tail, the eye portion especially, exhibit electrical phenomena in singular intensity. The natives of India have been long cognizant of the fact, excited feathers being playthings amongst their children; but they do not seem to have divined the cause.

Experiments.

First. A glass rod is excited and made to approach the knob of the gold-leaf electrometer ; the leaves separate.

Second. The same experiment with a rod of shell-lac.

Conducting and Non-conducting Bodies.

202. Electricity, like heat, travels more freely along some bodies than along others. Bodies accordingly said to be conductors or non-conductors. Cavendish computes the conducting power of water to be to that of iron, as 1 to 400,000,000. The following table contains bodies, and classes of bodies, arranged according to conducting efficiency.

Conductors.	*Non conductors.*
Metals.*	Glass.
Charcoal.	Sulphur.
Water.	Resin.
Alcohol.	Ice.
Damp air.	Shell-lac.
Vegetable and animal bodies.	Dry Gases.

203. No body a perfect conductor, or the contrary. Bodies vary in conducting power with variation in condition. Natural tendency to electric equilibrium. Insulation, in what consists, and how effected artificially. Non-conductors also insulators. Insulated conductors retain electricity.

204. Illustration of the statements first made. It is shown that the electricity can be readily drawn from a conducting body charged with it, by approaching to it the finger, or a metallic

* Comparative powers of some familiar, and electrically important, metals.

Lead.	Tin.	Iron.	Zinc.	Copper.
1.	2.	2·4.	4.	12.

rod. The approach of rods of glass or lac produce no such effect. Instantaniety of the electric spark. According to Wheatstone its duration is about $\frac{1}{1,152,000}$ of a second. Rapidity of electric motion inferred. Wheatstone makes out by direct experiment the velocity of electric movement through copper wire to be 288,000 miles in a second of time. Fizeau in France, and Mitchell in America, found it to be less than a fourth and tenth part of that amount respectively. Hygrometric differences in the atmosphere during the experiments might have to do with the disparity in the results; as also might unequal sensibility of mechanical contrivance. Wheatstone's mode of experiment seems to be particularly free from errors of an instrumental kind, and even of observation.* Contrivance by which Wheatstone succeeded in measuring the intsantaniety of the electric spark. Illustration by means of a disk, painted radially with the prismatic colours.

EXPERIMENTS.

First. A copper wire is suspended by a silk thread from the roof of the College. It is suspended by the middle, both ends hanging near the ground. One end has two parallel slips of gold leaf attached to it. An excited rod is presented to the free end: the gold leaves instantly separate.

Second. Demonstration by means of Wheatstone's revolving mirror.

Third. The copper wire has a portion cut off and re-attached by a silk thread —the excited rod presented as before—no repulsion between the gold leaves.

205. All bodies have electric states special to themselves,—subordinate to the two great classes, positive and negative. Classification of bodies on this ground. The earth and air, the great resevoirs of electricity; the former being usually charged negatively, the latter positively. Illustration by the dipping needle. Violent demonstration of the tendency to equilibrium, after long

* See also Faraday, *Phil. Mag.* for March, 1854, p. 201, *et infra.*

drought. Trees and animals being conducting media, often destroyed thereby.

206. The electric tension of the atmosphere owing, according to De la Rive, to the lower ends of atmospheric columns being hot, while the upper ones are cold. The currents are from the sun's parallel towards either pole above, and conversely below. The electric passage, through frozen spicula near the poles, probably produces the aurora.

The Electric Spark.

207. Otto de Guericke and Hawksbee first discovered that not only do vitrious and resinous bodies develope electricity when rubbed, but also that the development is accompanied by a cracking noise; and that, in the dark, flashes and sparks of light are observable. Similar phenomena often develope themselves under ordinary circumstances, such as sudden removal of worsted or silk clothing from the person, the stroking of the back of a cat, combing the hair, &c.

Experiment.

A student is placed on the insulating stool, and flapped with a silk handkerchief: he places his finger on the gold-leaf electrometer; the leaves separate.

Electric Polarity.

208. Term derived from the same root as that applied to the extremeties of the earth's axis. Meaning of the term pole in this case. Polarity by induction; in what consists and how produced.

Experiments.

First. An insulated metallic rod has pith balls suspended by moistened threads from its ends. It is charged with electricity, and that in the balls tested,—the one is found to be charged with positive, the other with negative electricity.

Second. The same with insulated conductors in presence of a charged conductor.

The Electric Machine.

209. Description of the Electric Machine, and the principles of its construction. The cylindrical machine. The plate machine. Their respective efficiency in producing electricity. Electric Induction. The Electrophorus. Construction and mode of action. Experiments with the same.

The Power of Points.

210. In what the power of Points consists. Interest attaching to this faculty, on account of its application to the protection of buildings, ships, &c. Laplace's law of electric tension, *i.e.* that it is "*directly as the density and inversely as the surface,*" *considered.*

Experiments.

First. The prime conductor is charged, and its discharge effected by the common discharging rod.

Second. The electric machine is put in action: a conductor with a spherical end is brought near to the prime conductor: the electricity flows towards it in a continuous stream.

Third. The arrangement as before. A current of electric sparks flows as in the former case. A pointed metallic rod is approached to the prime conductor; the current to the conductor first mentioned ceases.

Fourth. A metallic point is inserted in the prime conductor and the machine brought into action; the electricity is discharged silently and invisibly by the point.

211. Discussion of these experiments. Inference that a point is more suitable for drawing off electricicy than other forms. Franklin's experiment for drawing down electricity from the clouds; also, De Romos and Cross's experiments for the same purpose, and their results. Application of this property in points to the construction of lightning conductors. Their construction, and mode of application to houses and ships, described.*

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* A recent instance of the destructive effects of atmospheric elasticity may be given here. A schooner called the Alma, carrying a large quantity of gunpowder

212. Thunder house described, and experiments therewith.

213. If two spheres of equal diameters be in contact, two centres of greatest electric tension are found to exist at the points opposite to those of contact. If a sphere of greater diameter be in contact with one of less diameter, the maximum tension is similarly situated as before; but the tension, at the surface of the smaller sphere, is found to be greater than that at the surface of the greater. A series of equal spheres in contact exhibit corresponding results as in the first case. A series of spheres constantly diminishing give results corresponding to the second case. There are two loci of maximum tension in either case, viz., at the opposite extremities of the series. Accordance with Laplace's law, quoted above. Experiments confirmatory of these statements.

214. The polar states of conductors, and the power of points, deduced from phenomena developed in these experiments, in accordance with Laplace's law, quoted above.

215. Difference of the luminous appearances at the extremities of positive and negative conductors. In the former case a bright star appears, and increases as a pointed conductor is made to approach a ball charged positively; as it is made to approach a ball charged negatively, the star, which at first appears, changes to a brush, and ultimately breaks up into sparks.

The Leyden Jar.

216. Construction of the Leyden Jar. It furnishes a means of accumulating electricity. Discovered by a Dutch philosopher

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was blown up at Malacca, in November, 1855, during a thunder storm; and three only, out of the crew and six passengers, escaped death.

For further examples, see Harris on Thunder Storms.

who resided at Leyden, and hence the name. Attempting to electrify some water, contained in a phial, he unexpectedly experienced a concussion of the kind which now bears the name of the electric shock. The residual discharge in the case of electric jars of great capacity, to be guarded against; the quantity of electricity remaining after discharge, having been found to be about $\frac{2}{13}$ of the whole charge.

217. The tinfoil coating of the interior and exterior of the Leyden Jar not essential. Its function, the equal distribution of the electricity over the surface of the jar. The electric tension acts on the surface of the glass. If the charging be carried too far, the glass may be pierced.

Experiments.

First. The electric shock.

Second. A Leyden jar has a moveable metallic coating. When charged the coating is removed, and after a time replaced. The discharge takes place as usual.

Third. A bell Jar is moved about over a point from which a current of electricity flows; it is now placed over pith balls resting on a metallic plate; the balls dance.

Fourth. A jar is charged by a point as in the last case; the tin lining is then introduced, and the jar affords the usual discharge.

The Electric Battery.

218. Electric Battery exhibited, its construction explained, and experiment therewith.

219. Methods of measuring the strength of electric tension.

First. By the Quadrant Electrometer.

Second. By Coulomb's Torsion Electrometer.

220. Construction of these instruments described, and experiments illustrative of their use.

Additional Illustrations and Demonstrations, chiefly connected with the luminous phenomena of Electricity.—(Evening lecture.)

First. Luminous effects produced, by rubbing a cylinder of shell-lac with flannel; flashes of light are developed while the friction proceeds, and sparks are subsequently drawn from the cylinder.

Second. Sparks drawn from the electrophorus. Permanency of charge in this arrangement shown.

Third. Brilliancy of the flash from discharge, in the dark, of the Leyden jar.

Fourth. Current of electricity from the prime-conductor to the Leyden jar shown.

1*st.* The jar being insulated.

2*nd.* The jar being connected with the earth.

Fifth. Charge by cascade; showing that every spark, from the prime conductor to the knob of the first jar, is attended by one from the outer coating of that jar to the knob of the second jar, and so on. The reason of this occurrence explained.

Sixth. Brilliancy of the passage of a current of electricity through a tube studded with circular patches of tinfoil, arranged spirally, from end to end of the tube, and at small distances from each other, shown.

Seventh. The "Electric Word."

221. Description of the Aurora Borealis. High probability of its nature being electric.

Eighth. A discharge of electricity is passed through a vacuous tube; showing at once a mimic Aurora, the coercive power of the atmosphere upon electricity, and the inherent repulsive power of the constituents of the fluid itself.*

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* For researches on electric discharges in vacuum, see M. Quet, *Comptes Rendues* for December, 1852.

222. The conducting power of water, and hence of an atmosphere saturated, evidenced in the lightning flash. The union of the opposite electricities of the earth and air then effected, probably destroyed again by the friction of dry atmospheric currents on the earth's surface.

Ninth. A mimic lightening flash produced, by conducting a charge of electricity through a line of water, drawn on glass.

Tenth. The chime of bells. The transfer of opposite electricities, from the outer to the centre bell and reciprocally, proved by the attendant flashes of electricity given out on contact of the hammers with either, alternately.

Eleventh. The luminous phenomena attending the discharge of electricity of both kinds, by pointed and by rounded conductors, shown.

Twelfth. A student is placed upon an insulating stool and electrified; sparks are then drawn from different parts of his body, and æther inflamed by the of his finger.

Thirteenth. Gunpowder ignited by the electric spark.

CHAPTER XII.

GALVANISM, OR VOLTAIC ELECTRICITY.

223. Sultzer's discovery in 1767, that a slip of one metal under the tongue, brought in contact with that of a slip of another over it, produces a saline taste. Influence of electricity in producing convulsions in the limbs of frogs, established by Galvani, professor of anatomy at Bologna. Circumstances connected with the discovery. Theory of Galvani. The branch of science, which has sprung from these discoveries, commonly called Galvanism, in honor of Galvani. Professor Volta of Pavia pursues the experiments and explains the phenomena, tracing them to electricity. He proves that the animal nerve or muscle is not essential to the result. He shows that two different metals in contact, take on electric states which are the opposite of each other, the one being positive, the other negative. He reproduces Galvani's phenomena, by means of two such metals.

Experiment.

A dead frog has a wire passed under the crural nerve; the legs of the frog are laid upon one end of a slip of zinc, which the wire touches, its head upon one end of a slip of copper, not in contact with the zinc; the limbs of the frog become convulsed when the free ends of the metallic slips are connected by a wire.

Voltaic Circle.

224. Voltaic Circle, how constituted. A voltaic circle composed of a plate of zinc and one of copper having each one end immersed in dilute acid, (the ends immersed being apart from each other,) the other ends rising above it. Sulphuric acid,

diluted with about 16 times its bulk of water, answers very well as a liquid element. No action takes place so long as the free ends are apart; when brought together gas is discharged at the copper. Direction of the current. Terms positive and negative electrodes, now applied to the zinc and copper elements respectively, and electrolyte to the fluid element. High and low tension, in what consist.

The Voltaic Pile.

225. Volta contrived the pile which bears his name. In this several simple elements are combined together, whereby marked effects are produced.

Experiments.

First. The Voltaic pile has moist conductors, formed of pieces of cloth dipped in muriate of ammonia, placed between the pairs. Voltaic commotion produced in the human system, when the poles are grasped one in each hand, shown.

Second. The effect on a frog, prepared as in the first galvanic experiment, shown.

Third. A Leyden jar charged from the positive pole of the pile.

226. Table, containing a few substances, arranged according to their galvanic relations,—each being positive to all which follow it.*

1. Amalgam of Zinc	4. Lead	7. Gold
2. Zinc	5. Copper	8. Charcoal
3. Iron	6. Silver	9. Platinum.

227. Biot's experiment, showing the mutual attraction of the terminal wires of the pile. Correspondence between these effects and those produced by the Electric Battery, pointed out. The tension of the Voltaic electricity dependent on the number of

* Appendix, note S.

pairs, its quantity on their size.* In a pile divided into four by vertical sections, each of the parts would have the same tension at its extremities as before, since the quantity on the surface would have the same proportion to the surface as before. If the four parts were put above each other, there would now be a much greater quantity at the poles, and a less surface. Hence, and in conformity with Laplace's law, the quantity is as the surface, the intensity as the number of the pairs.

Volta's Couronne des Tasses.

228. This arrangement exhibited and described. The containing vessels, small tumblers; the metallic elements, copper and zinc; the fluid element, dilute sulphuric acid. The terminal wires being brought into contact, hydrogen gas is evolved from the copper electrodes in the tumblers.

229. Improvement in the original construction of the pile by Cruikshanks. He cements the pairs of plates, and fits them into a wooden trough. Subsequent improvements. Forms now mostly used:

Smee's Battery, Daniell's Battery, Grove's Nitric Acid Battery, Bunsen's Battery, the Maynooth Battery.

230. These forms exhibited, and their construction and special fitnesses explained.

231. The following liquid elements will be found to answer well generally for the batteries.

Smee's Battery.

Sulphuric acid	1 oz.
Water	10 oz.

* Appendix, Note T.

Daniell's Battery.

Zinc cell: as in Smee's battery.
Copper cell: saturated solution of sulphate of copper.

Grove's, Bunsen's, and Maynooth's Batteries.

Zinc cell:	Muriatic acid	1 oz.
	Water	$2\frac{1}{2}$ oz.

Platinum, Charcoal, and Iron cells: equal parts of sulphuric and nitric acids.

N.B. All the above parts are by measure.

The Voltameter.

232. The Voltameter is an arrangement for determining the decomposing power of a battery. Description of the Voltameter, and mode of application of the same.

Experiment.

Decomposition of water by the Voltaic battery; the water being acidulated by addition of about an eighth part of its volume of sulphuric acid.

The Galvanometer.

233. Its construction and use. Remarkable power possessed by galvanic electricity, upon which it depends. Deflection of the Needle under the influence of the voltaic circuit, shown.*

Luminous Power of Voltaic Electricity.

234. Brilliancy of the discharge between charcoal points; this light the greatest which art can produce. According to Professor Wärtmann's experiments, the light produced by a Bunsen's

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* See *Phil. Mag.* for April 1854, p. 298.

battery of fifty pairs, is distinctly visible at the distance of ten miles.

Experiments.

First. Electric spark, on making or breaking contact between the conducting wires of the voltaic circuit, shown.

Second. By the electric spiral.

Third. Discharge between charcoal points.

Heating Power of Voltaic Electricity.

235. The passage of voltaic electricity through bodies raises their temperature. Water may be made to boil by this means. Metals offer different resistances to the passage of voltaic electricity through them. In a compound wire, those parts offering greater resistance are heated, whilst the others remain cold.

Experiments.

First. A wire made up of segments of platinum and silver, alternately, has the platinum portion raised to a red heat, while the latter remains cold.

Second. A fine platinum wire, forming part of the voltaic circuit, is carried through a small portion of water,—the water is speedily heated.

236. Intensity of voltaic heat greater than is producible by any other known means. The heat given out, according to Joule, by the oxidation of a gramme of copper 594° C. of zinc 1185° C. of hydrogen 33,553° C.* Fusion of the most refractory metals readily effected thereby. Application of the heating power of electricity for blasting in mines, blowing up sunken wrecks, for the clearance of rivers, roadways, &c. The Calorimotor.

Experiments.

First. The heating of wires of different metals to redness or fusion.

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* See *Phil. Mag.* for 1852, p. 481.

Second. The burning of a fine iron wire, connected with one pole of the battery at the surface of mercury connected with the other pole.

Third. Deflagration of metallic leaves by introducing them into the voltaic circuit.

Fourth. A small charge of gunpowder has a fine platinum wire passed through it;- the wire is now introduced into the voltaic circuit,—the gunpowder explodes.

Fifth. Explosion of gunpowder under water.

237. Zantedeschi finds that equal currents, each of them singly capable of raising a wire to white heat, do not do so if passing through it in opposite directions at the same time; hence, he argues, the similarity in being of electricity and light.

MAGNETISM.

238. As it exists in natural magnets. Demonstrations. Natural magnets have poles. Methods by which magnetic power may be communicated to steel bars. Leading phenomena of magnetic attraction and polarity explained and demonstrated by experiment. Induction. Permanent and temporary magnets.

Magnetism of the Earth.

239. The Earth, a great natural magnet, the poles of which lie nearly north and south. Magnetic meridian. Declination, dip, variation.* Perturbations arising from the action of the aurora borealis; doubtless from that of the aurora australis also. Declination and dip needles. Intensity, how determined. Law of intensity—*directly as the quantity, inversely as the square of the distance.*

Experiment.

A rod of soft wire, four feet long, is arranged parallel to the dipping needle. It is tested and found to be and to continue while in that position, strongly polar.

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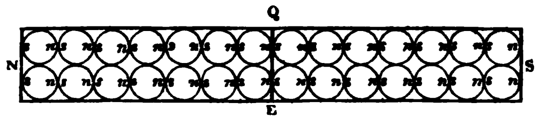
* For a table and instances of variation, see Golding Bird and Brook's Natural Philosophy, fourth edition, p. 270.

240. *Imagined structure of a bar magnet.*



N the austral, S the boreal poles of the magnet, *i.e.* the poles which, when the magnet is free, point north and south respectively.

E, Q, the equator of the magnet.

241. Mariner's Compass. Brief outline of its history. Its importance to commerce, and to the spread of civilization. Forms ordinarily used.

MAGNETIC POWER OF VOLTAIC ELECTRICITY.

242. The nature of the magnetic power of the electric current first ascertained by Oersted, a Danish philosopher. He proves that it is to be sought for in the closed circuit, not like other electric powers, at the pole of the interrupted circuit. Production of rotation in a magnet, under and over which a voltaic current is made to pass, re-adverted to.

EXPERIMENT.

A magnetic needle is so supported on a pivot as to lie in the middle of a wire rectangle. When the rectangle is introduced into the Voltaic circuit, the needle is deflected from left to right, or from right to left, according as the current is made to pass above or below it.

243. The magnetic power of electricity acts tangentially. Proof of this furnished by Oersted's experiment, whereby it is shown to act in the plane of motion of the needle, at the circumference of a circle described about the wire, and at right angles to the wire.* The magnetic power of electricity not arrested by glass. Great magnetic power obtainable by Voltaic electricity.

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* Appendix, Note U.

Experiments.

First. A steel needle is placed within a glass tube, around which a helix of copper wire is wound; a voltaic current is passed through the wire; the needle starts to the axis of the tube and remains suspended there. The needle has become permanently magnetic.

Second. A voltaic current is made to circulate round a horse shoe of soft iron; the iron is found to have become a powerful magnet. When the current ceases, the magnetic property ceases also.

Third. A voltaic pair is so arranged as to float in water, the connecting wires forming a loop above it. A permanent magnetic bar is presented to the loop, which advances to the centre of the bar and remains there. The magnet is now withdrawn, and the opposite pole introduced within the loop. The loop now retreats, passes off the magnet, turns round, and again advances as in the first case.

Fourth. The conducting wire of the last experiment, formed into a cylindrical spiral. It takes up a stable position in the magnetic meridian.

Fifth. Rotation of the pole of a magnet round a conducting wire, and reciprocally.

Voltaic Induction.

244. Power of induced voltaic currents. Professor Faraday discovers the means of developing such currents, and constructs apparatus for showing their nature and intensity. Mode by which such induction is effected. Powerful shocks producible by this means. Arrangement for this purpose shown, and its construction described. Experiments performed in illustration.

Identities of Magnetism and Electricity.

245. Statement of the question. Effects producible by the aid of suitable arrangements, from the magnet itself, corresponding with those from the voltaic circuit; such as magnetic induction, the contraction of the muscles, the spark, decomposition of water &c.

Experiments.

First. Iron filings are attracted by natural and by artificial permanent magnets.

Second. The same effect produced by a horse shoe of soft iron, round which a current of Galvanic electricity is passing.

Third. The force of the permanent magnet is shown not to be arrested by glass.

Fourth. The same is shown by the temporary magnet.

Fifth. Induction produced by the permanent magnet.

Sixth. The same produced by the electro magnet.

Seventh. The attraction and repulsion of unlike and like poles of a magnetic bar, by the permanent magnet, shown.

Eighth. The same with the electro magnet.

Ninth. The lines of magnetic force shown by means of the permanent magnet.

Tenth. The same with the temporary magnet.

Eleventh. The spark produced by the magneto-electric machine.

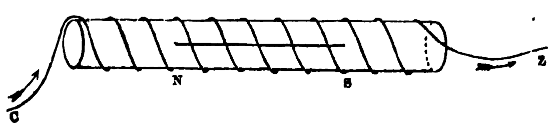
Twelfth. The shock produced by the same apparatus.

Thirteenth. Contraction in the muscles of a frog produced by the permanent magnet.

Fourteenth. Temporary and permanent magnets, made by means of electric currents, and of permanent magnets.

246. Discussion of the above experiments.

247. Situation of the north and south poles of the magnet in experiment first.



C the conductor from the copper electrode.
Z ,, ,, to the zinc ,,
N, S the north and south poles, respectively, of the magnet within the coil.

Electricity in Animals.

248. The Torpedo; the Gymnotus Electricus. Strength of shock which the latter can command. Mode of catching the Gymnotus practised by the American Indians, as described by Humboldt, quoted.

Diamagnetics.

249. Important discovery of Professor Faraday that most, if not all substances, mineral, animal and vegetable, are subject to magnetic influence, though the effects produced be of different kinds, ranging themselves under the two great heads, Magnetics and Diamagnetics; the latter term signifying, that the effects which the magnetic force produces, in the class which it designates, are the opposite of those produced in substances comprehended under the former term. Thus, if the line joining the magnetic poles of a horse shoe magnet be called the line of magnetic force; and, if a bar of iron be suspended horizontally at the middle of this line, but making an angle with it, by a fibre of silk, the bar will turn round till it coincides with that line. If, instead of the iron bar, one of bismuth, or glass, of vegetable, or of animal substance, similarly suspended, be brought near the line of magnetic force, its ends will be repelled from that line, and the bar will finally take up its position at right angles to it. Dr. Faraday gave the terms axial and equatorial to these two positions respectively. "Were a human being freely suspended between the poles of a powerful magnet, his head being towards one pole, his heels towards the other, he would rotate and take up the equatorial position."

Experiments with bars of iron, glass, vegetable and animal substances, in illustration and proof of the effects of the magnetic and diamagnetic forces.

CHAPTER XIII.

APPLICATIONS OF VOLTAIC ELECTRICITY.

250. Singular rapidity of the growth of Electrical Science. The variety, interest, and importance of its economic uses, entitle them to separate consideration.

As a Motive Power.

251. Sanguine hopes formerly entertained on this subject. Professor Jacobi of St. Petersburgh constructs a boat capable of accomodating five persons, and propels her by the magnetic power of Voltaic Electricity. Grounds of abatement of the expectation that electricity would be found generally available as a motive power. Progress made in this application of it.

Experiments.

An Electro-dynamic machine exhibited, its construction described, and its action shown by experiment. An electro magnetic coil machine, for medical purposes, shown and described, and the increased intensity of voltaic action, due to induction, demonstrated by experiment.

As a Gilding Agent.

252. Voltaic Electricity employed for superimposing a coating of costly metals over vessels of inferior metals, medallions, statues, &c. Extreme delicacy of the results adverted to. Delicate flowers may be thus covered with a metallic crust, the form

of the flower remaining unaltered. This application of Electricity has grown up within a few years to considerable economic importance, as a distinct branch of manufacture.* Name electro-metallurgy given to this art. Principles involved in the operation explained, and the mode thereof shown. Necessity of permanency in batteries used for this purpose. Necessity of sustained saturation in the solution of the metallic salt employed, in any given case, for such purposes. Means by which this is effected, explained. The battery should be so arranged that the electric current flow in a direction at right angles to the magnetic meridian, and from east to west, since then the inductive power of the earth co-operates with the battery; but if otherwise, against it.

As a Moulding or Printing Agent.

253. Galvanic electricity employed in the fabrication of plates from engravings. Method of its application in such processes. Efficiency of electricity for such purposes. Name electrotype given to the products. The price of prints from electrotype plates, to that of those from engraved ones, about 1 to 10. Importance of this fact as placing copies of works of high art within the reach of the poorer classes, and thus refining and elevating their tastes. Application of the same agent for the production of metallic medallions, &c., from gypsum and other casts.

Experiment.

A solution of sulphate of copper in water is connected with the copper pole of a battery, and a slip of silver or platinum terminating the wire of the zinc pole is plunged into the same liquid; the silver submerged is speedily covered with copper.

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* The making and coating of types and stamps by electric agency is extensively practised at the Semundra Orphan press, near Agra, with profit and success. Specimens of these enriched the display on my lecture days, and gave practical interest to my demonstrations.

As a Vermifuge.

254. Voltaic agency occasionally employed for preventing the ravages of minute reptiles, and such unwinged insects as the white ant, so destructive in this country. A small plate of copper is placed on a large one of zinc, so that there may be a free margin of the latter; when an insect or reptile attempts to climb up from one to the other, it receives an electric shock which projects it back. Without care in keeping the plates clean, the protective power of the arrangement fails, as a coating of oxide dulls its action. The common earthworm particularly sensible to electric influence.

Experiment.

A disc of copper of four inches diameter has one of zinc three inches in diameter superimposed, leaving a free margin of one inch; small reptiles are placed upon the copper, and when in their movements they touch the zinc, they are repelled by the shock which they receive.

As a Mining Agent.

255. This application of electricity already adverted to, in treating of the heating effects of electricity. Advantages which it confers on the miner, by affording him a safe and unfailing means for the discharge of explosive compounds. Mode in which it is used for such purposes, described. Employed also for exploding gunpowder under water. Advantages of this adaptation to navigation and commerce; method by which obstructions in roadsteads and harbours are removed, described. Removal of the wreck of the Royal George from Portsmouth harbour, by Colonel Pasley.

Experiment.

A bottle is charged with gunpowder, and through the charge a fine platinum wire, uniting the two poles of a battery, is made to pass. The bottle is now submersed under water. Connection is then made with the battery,—the gunpowder explodes.

As a Telegraphic Agent.

256. Astonishing results already attained in this application of Electricity. Extent to which the Electric Telegraph has been carried in America. The same speech may, while yet delivering at New York, be printing at Boston; a circumstance affirmed as having occurred. This application of electricity, like the mining one, suitable for land or water. Human thought or feeling, primarily communicated by certain sounds, aided, in the case of the dumb supplanted, by certain understood motions. In order to convey throught to a distance, in space or time, conventional forms employed. Communication by the Electric Telegraphs at present in use, effected in two ways, by motion and by form.

First. The Needle Telegraph.—If a current of electricity be made to pass over and under a magnetic needle, it causes its deflection from left to right; if it be, on the contrary, made to pass under and over the needle, it causes its deflection from right to left. Oerstead's experiment repeated. We have here at once two letters or two words of electric language—the first motion may be taken to signify A, or yes, the second B, or no, for instance: so two movements to the right may be made to stand for C, or any word or words arbitrarily adopted: two to the left D, and so on. A model of this Telegraph described, and demonstrated with. Its capabilities, disadvantages, and defects considered. This telegraph used in India.

Second. The Disk Telegraph.—The action of this telegraph depends on the attractive power of electricity. A lever is alternately attracted and released by a temporary magnet, and by acting on an escapement, causes the revolution of a disk, upon which the letters of the Alphabet, numerals, &c., are painted; this, though situated at one end of the line of communication, is under perfect control at the other, so that it may be made to exhibit any letter, and consequently to communicate any

word at will; the length of the line of communication being, within certain limits, of no moment, either with regard to this or the needle telegraph. Description of a model of this telegraph, and demonstrations therewith.

Third. The Printing Telegraph.—In this invention the communications are printed by galvanic agency; it is of great promise and appears to excel, in point of rapidity and accuracy, all other forms.* Arrangement described.

EXPERIMENT.

A small copper cylinder, coated over with paper which has been dipped in a mixture of starch and iodide of potassium, is connected with the zinc pole of a battery. It is found that by means of the terminal wire of the other pole, brilliant blue characters may be traced at will.

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* This kind of telegraph is that chiefly used in America, and is about being introduced into India.

CHAPTER XIV.

OPTICS.

257. Definition. Hypothetical views on the nature of light. The emission theory. The wave, or undulation theory. The former due to Newton, the latter to Descartes. Strong confirmation of the latter being the true one, in the admirable identity between the results of experiment and of mathematical investigation. Necessity for the existence of an ethereal medium, pervading the universe, to this theory. Such a fluid, however rare, would in time diminish the orbits of planetary bodies, by opposing the tangential force. Encke's comet. It revolves round the sun in 3·3 years. A diminution of 1·8 days, during 52 years, has occurred in its period of revolution. Argument supplied by this fact in support of the theory. Analogy between the nature of light, according to this theory, and that of sound.

The Velocity of Light.

258. Astonishing celerity of this agent of communication between sentient beings. High importance of the swift propagation of light to most, if not to all creatures, for their sustenance and preservation. The privilege conferred thereby on man, whose thirst after knowledge, and aspirations after advancement in his destiny, make the heavens an especial object of his interest and admiration. Intelligence of celestial phenomena, thence obtained by him, of sufficient accuracy for his physical and moral wants. The velocity of light, as already stated, about

192,000 miles a second; that is, it travels about 691 millions of miles in an hour—a velocity nearly a million of times greater than that of sound.*

259. By the *emission theory*, a ray of light consists of a line of particles projected from the luminous body to the eye. By *the undulation theory*, a ray of light consists of a series of undulations, excited by the luminous body and propagated onwards till they reach the eye. The former implies ultimate exhaustion and universal night,—the latter admits of permanent action. Hence the wave theory more consonant with our experience of the manifestations of Divine power. The progress of experimental research towards the establishment of the latter theory is a magnificent monument of human ingenuity and genius.

Rectilineal Propagation of Light.

260. A sphere interposed between a window and a screen or wall, casts a circular shadow on the wall. A cube with opposite sides, parallel to the window and wall, throws a square shadow. A man standing between them has his profile displayed on the wall. The shadows in these cases represent sections of the objects causing them. The ascertainment of the height of the sun from the length of shadow of a known object; and, reciprocally, of the height of an object from the length of its shadow and the known height of the sun, were determinations familiar to ancient geometers. This fact shows that, in their times also, the rays of light were believed to be transmitted in straight lines. A group of rays, proceeding together in the same direction, called a pencil of rays. The following demonstration shows how the heights of objects are determinable from the horizontal lengths of their shadows.

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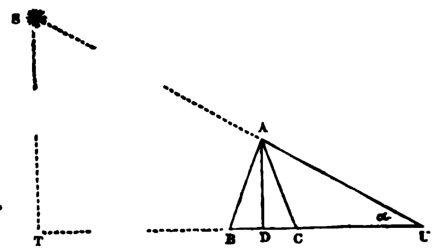
* Appendix, Note V.

Let ABC be a pyramid, S the sun, of which α is the angular height; at U the extremity of the shadow $\frac{BU+CU}{2}$ gives DU: hence D the foot of the axis is known; therefore $AD=DU \tan \alpha$ gives AD the height; conversely, AD being given α is found, which goes directly to the problem of the obliquity of the ecliptic.



Experiments.

First. A sphere is suspended in a darkened room, between a light and the opposite wall; the shadow cast by it is a circle.

Second. A cone is suspended as in the first experiment; the shadow is a triangle.

Deductions from the Experiments.

First. If the light from a luminous sphere be intercepted by an opaque and non-luminous one, of equal magnitude with itself, the shadow will be a cylinder.

Second. If the light from a luminous sphere be intercepted by an opaque and non-luminous one greater than itself, the shadow will be the trunc of a cone, the apex of which lies on that side of the luminous body remote from the other body.

Third. If the light from a luminous sphere be intercepted by an opaque and non-luminous one less than itself, the shadow will be a cone, whose apex lies on that side of the opaque body remote from the luminous one.

Note. *The length of the shadow, in the last case, increases with the distance of the opaque sphere from the luminous one.*

263. Geometrical illustrations of the deductions. The difference between the lengths of meridian and ante and post-meridian shadows, and the variation in the duration and magnitude of eclipses, due to these facts.

Intensity of Light.

262. Light decreases, in intensity, in proportion to the inverse square of the distance from the luminous body. If a board of one foot square be suspended half way between a small opening in a window and a wall, it will cast upon the latter a square shadow, the area of which will be four square feet. Geometrical verification of the same law.

263. A luminous point being viewed as a centre, equal distances around it will be equally lighted, be they near or remote. If we go round a light, above it or below it, we find it always equally bright, provided only that our eye be at the same distance from it, and that the luminous object be equally bright on all sides. Such distances may be represented by the surfaces of concentric spheres; and these are, to each other, as the squares of their radii. Hence the intensity of light, distributed over similar portions of those spheres, will be inversely as the squares of the distances. Experimental results prove the same. Apparatus for measuring the relative intensity of light called Photometers.

Ritchie's and Wheatstone's Photometers described and experimented with.

Reflection of Light.

264. Light traverses space in straight lines. If a pencil of light impinge upon any body, a portion is reflected from the surface, and describes a path making an equal angle, and in the same plane, with the perpendicular to the surface at the incident

point, which the path of the impinging ray did; according to the law—

The angle of incidence is equal to the angle of reflection.

Penetration of Light.

265. The portion of a pencil of light, which is not reflected from the surface of a body, enters into its mass; through which it either partly passes, or becomes entirely absorbed. All bodies absorb more or less light. At a depth in the clearest sea of 150 feet, the light of the sun would, it is estimated, be no greater than that of the moon. Bodies are respectively termed *transparent*, *translucent*, or *opaque*, according as—

First. Objects can be distinctly seen through them.

Second. Light, but not distinct objects may be seen through them.

Third. Neither objects nor light can be seen through them.

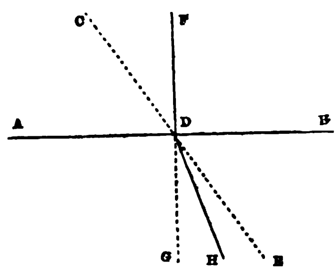
266. Bodies of different reflecting powers may be so arranged, that two or more images of the same luminous body may be obtained. This principle availed of in the construction of an ingenious instrument called the Depleidescope, invented by Mr. Dent of London, for determining the meridian passage of the sun. Description of the instrument.

Penumbræ.

267. Shadows of objects cast upon planes, or the shadow of the earth cast upon the moon in lunar eclipses, have not finely defined edges—the pure shadow blends off on either side into the unsubdued light. The portion between the light and shadow called the Penumbræ. Explanation of the cause of this phenomenon.

Refraction of Light.

268. A ray of light passing from one medium into another, as from air into water, is deflected from its course at the surface of the second medium. This deflection is termed the refraction of the ray, and its amount is different for different substances. If the ray pass from a rarer to a denser medium, it is made to approach the perpendicular to the surface at the incident point; if it pass from a denser to a rare medium, the opposite effect is produced. The plane of refraction is that of the incident ray and perpendicular, being analogous to the plane of reflection.



Let AB represent a portion of the surface of a fluid, CD a ray of light impinging on it at D, and having the direction CDE. Draw FDG perpendicular to the surface at D. The ray will leave its path at D and describe the new one DH, which will lie nearer to DG or to DE, according as the refracting fluid is more or less dense. If CD coincide with DF there will be obviously no refraction. If the ray proceeded primarily in the direction HD it would be refracted into DC, or from the perpendicular. The ratio of the sines of the angles of incidence and refraction, in any body from the standard medium, gives the refracting power of that body, and is termed its co-efficient of refraction. Critical angle.*

Experiments.

First. A coin is placed on the bottom of an empty basin, about which a ring of students is formed, who can see but a part of one edge of the coin; water is now conveyed into the vessel, by means of a syphon tube; the coin gradually rises into full view of all.

Second. The same experiment, but with water saturated with common salt.

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* Appendix, Note W.

Cor. If the fluid, by which the ray CD is deflected, increase in density from D downwards, the line DH will be a curve.

Refraction through Lenses.

269. The direction which rays take, on refraction by lenses, deducible from the experiment. Description of the different forms of lenses, and of their respective properties, illustrated by means of lenses and models.

Laws.

First. The direction of rays, refracted by a prism, is from the angle of the prism.

Second. The direction of rays, refracted by a convex lens, is towards the axis of the lens.

Third. The direction of rays, refracted by a concave lens, is from the axis of the lens.

Atmospheric Refraction.

270. Light passing from the space beyond, into our atmophere, necessarily refracted. The density of the atmosphere decreases upwards, from the earth's surface, according to a law already explained; consequently a ray of light from a heavenly body, as the sun, is deflected continuously during its course through our atmosphere. Such bodies appear to occupy a position in the celestial vault higher than the true one. The greater the distance through which the ray travels, and the denser the atmosphere at the time, the greater will be the displacement. Heavenly bodies near the horizon suffer greater displacement than those more remote from it. Apparent compression of the lower limb of the setting sun. Sir J. Ross found the difference between the sun's vertical and horizontal diameters at setting to be 5′ 21″

the former being 27′ 10″, the latter 32′ 31.″ The observation was taken at 65° 22′ S. and the time 11h. 56m. Eclipses of the moon at sunset. Corrections necessary to be made for refraction, in determining the true place of a heavenly body, explained.

271. The refracting power of bodies has obvious dependence upon their density. Combustible substances, however, of a given specific gravity are more highly refracting than those of corresponding gravity which are not combustible. Newton's inference from this fact as to the nature of the diamond. Classification of substances according to their refracting power.

Table containing a few of the more remarkable substances, arranged according to their refracting powers.

Diamond	2·755	Alcohol	1·372
Flint glass	1·600	Human eye, cryst. lens	1·384
Alum	1·457	Tabashere	1·114
Sulphuric acid	1·434		

272. According to Newton's theory, light should be accelerated by refraction through a dense medium. Arago suggests that this condition be subjected to the test of experiment. Foucault follows up the suggestion, and demonstrates that it is, on the contrary, retarded.*

Colour.

273. Endless variety of colour in nature. Colour being seen only in the light, suggests that it is inherent therein. This suggestion confirmed by experiment. A ray of light made to pass

* For a detail of these admirable experiments, as also those of M. Fizeau on the direct problem of the velocity of light, see Pouillet's Physique, 6th edition.

through the opposite sides of a cube of glass, or a prism with parallel sides, falls unaltered on a screen beyond. If the same ray be made to pass through a triangular prism, one of the faces of which is held perpendicular to the ray, it will fall on the screen unchanged in dimension in the direction of the longer axis of the prism, but greatly elongated in that of the shorter one, having assumed an oval form. It is no longer white, but made up of singularly brilliant groups of coloured rays, the co-efficient of refraction differing for each group.

Experiments.

First. A ray of light is made to pass through a prism with parallel sides, and is received upon a screen behind; the ray is found to be unchanged.

Second. A ray of light is made to pass through a triangular prism held horizontally, and is received upon a screen, as in the last case; it is found to be elongated in a direction across the prism, and to be vividly coloured.

274. The colours are seen to be seven; which, in the ascending order of their refrangibility, are red, orange, yellow, green, blue, indigo, and violet; also a ray only visible under certain conditions, lying without the violet.* These may be termed primary and binary. The primary colours are red, yellow, and blue; the binary, orange, green, indigo, and violet. The primary cannot be formed by union of any, or of all the others; the binary may be formed from the primary. The colour, compounded of any two of the primary colours, is the complement of the third colour; thus green is complementary to red, orange to blue, and violet to yellow. Fraucnhoffer's Lines.†

275. Newton found the relative distances of the rays of the spectrum, from a point situated at a distance from the red ray

* See Professor Stokes on the invisible ray, *Phil. Maga.* for 1852, vol. 4, p. 388.
† See *Phil. Maga.* for May 1855, p. 327.

equal to the breadth of the spectrum, (*i.e.* the distance between the extreme red and extreme violet ray,) to be

$$1,\ \tfrac{8}{9},\ \tfrac{5}{6},\ \tfrac{3}{4},\ \tfrac{2}{3},\ \tfrac{3}{5},\ \tfrac{7}{16},\ \tfrac{1}{2},$$

The unit being the distance from the point above-mentioned and the extreme violet.

In these numbers, remarkable analogy between sound and light is perceptible.*

Experiments.

A refracted ray is separated between the yellow and blue elements;—these being allowed subsequently to unite, the product of the union is green.

Refrangibility of the rays of the Spectrum.

	Water.	Flint Glass.
	Index of Refraction.	Index of Refraction.
Red	1·3310	1·6277
Orange	1·3317	1·6297
Yellow	1·3336	1·6350
Green	1·3358	1·6420
Blue	1·3378	1·6483
Indigo	1·3413	1·6603
Violet	1·3442	1·6711

Recomposition of White Light.

276. As a ray of white light may be resolved into its coloured elements, so, conversely, the latter may be recomposed into the former. No doubt, if natural accuracy could be obtained by man, the colour white might be produced by the mixture of red, yellow, and blue. The nearest approach to this result far from accurate. Newton paints colours corresponding with those of the spectrum on the margin of a wheel; the wheel being made to revolve rapidly, its coloured margin appears greyish white.

* See *Comptes Rendues*, No. 3, January 1855.

Experiments.

First. A ray of light is refracted by a prism ; a corresponding prism is applied so that the two form together a quadrilateral prism with parallel sides; the ray passes through unchanged.

Second. A ray of light is refracted by a prism, the coloured rays are received upon a double convex lens, the focus of which is on the surface of a white screen ; between the focus and lens the elementary rays are found to be distinct ; in the focus white light has been reproduced.

Third. A wheel, around the margin of which the primitive colours are painted, is made to revolve rapidly ; its painted margin becomes a dull white.

The Rainbow.

277. The phenomenon of the rainbow due to the refraction of the sun's light by drops of rain. Similar phenomena produced by the spray of waterfalls. Rationale of the phenomenon.

Diffraction and interference of Light.

278. If a ray of sun light be admitted through a pin hole into a closed room, and a small opaque body be introduced into its path, the ray suffers an inflection or bending from its path, called diffraction. It is found that the confines of the shadow are adorned with bands of different colours, repeated, but becoming fainter and fewer in number, as they recede from the shadow.

Experiments.

First. Look straight at the light of a candle with eyes nearly closed, and you will see interference bands running parallel to the flame, or in the direction of, and along lines perpendicular to, the eye lashes, by which they are caused.

Second. Look at a light through a secondary feather of a bird's wing, as for instance that of a pigeon, and you will see interference bands lying parallel to the fibrils, by which they are produced. The large secondaries of the Peacock's wing develope splendid bars of this nature. Some feathers, such as the tail feather of the pheasant, give two sets of fringes crossing each other.

Third. Examine through a pin hole in tinfoil the image of the sun in the interior of a watch glass, which has been blackened on the outside by a coating of black sealing wax dissolved in spirits, and it will appear to you surrounded by rings, which arise from the interference of the rays passing through the minute opening; the same with the image of the sun on polished metallic spherules, such as the bulb of a thermometer, or a globule of quicksilver.

Fourth. A ray of light, admitted through a pin-hole in a window shutter, is received upon a white screen; a fine tube blackened in the interior is suspended in the ray; the shadow is found to be fringed with groups of coloured bands.

Fifth. A sewing needle is suspended as in the last case; the result is the same as in that experiment.

Sixth. A hair is stretched across the centre of the pupil of the eye; on now looking at a light a line of beautiful and sharply defined fringes is seen to extend symmetrically on either side of, and at right angles to the hair.

Note. The fringes are as follows:—

First fringe. Violet, indigo, pale blue, green, yellow, red.

Second fringe. Blue, yellow, red.

Third fringe. Pale blue, pale yellow, red.

279. An elementary ray, diffracted in the above manner, retains its colour in the fringes; they are now divided by dark intervals. The shadows found to be also divided by bands. These bands due to the interference of rays of light with one another. Instead of using elementary rays, we may examine the coloured fringes through tinted glass.

Experiments.

First. An elementary ray is diffracted as in the former experiments, and the fringes examined; they are found to extend into the shadow.

Second. The light on one side of the diffracting body is intercepted, the bands disappear from the shadow; showing that the fringes in the bands were due to the rays on one side interfering with those on the other.

280. If two pencils of light, radiating from neighbouring points, fall on the same spot, they are said to interfere with each other If the distances of the radiant points from the point of interference be the same, the pencils will there form a bright spot or fringe of light on a screen. They form a bright spot also if the distances be as 2, 3, 4, &c. If the distance be as ½, 1½, 2½, 3½, &c., they produce a black spot. Geometrical illustrations.

281. Wertheim produces double refraction in isotropic bodies by pressure and traction, and shows the phenomena of interference; he proves that the tints in Newton's rings are due to the difference of path of the rays producing them.*

EXPERIMENT.

Light is admitted through two pin-holes into a darkened room, the screen being so placed that the bases of the luminous cones interfere at their margins; illumination and darkness are produced within the limits of interference.

282. The phenomena of colour, by interference of rays, shown by superposition of thin plates of different transparent substances on each other, as for instance mica. In this case, the rays reflected from one surface interfere with those reflected from another. The brilliant colours of the shells of fishes due to their laminated structure. Newton's rings, an ingenious contrivance for illustration of this subject. The arrangement exhibited, and the construction described. Colours of thick plates.†

DOUBLE REFRACTION AND POLARIZATION OF LIGHT.

283. Substances of regularity of structure produce a physical change in a ray of light passing through them. In some the ray

* See *Phil. Maga.* for October, 1854.
† *Phil. Maga.* No. 2, of 1851.

does not pass out as it entered, but is divided into two parts. One of the parts continues to obey the ordinary law of refraction, lying in the plane of incidence, the other does not: they are called, respectively, the *ordinary* and *extraordinary* ray. A crystal of calcareous (Iceland) spar exemplifies this property in a very striking manner. Positive and negative crystals.* Axes of crystals. Axial planes. Demonstrations by means of dissecting models.

Experiment.

A crystal of calcareous spar is placed upon a fine line, drawn on paper, the line not coinciding with the axial plane of the crystal; two lines are now seen.

284. The ray of light divided by double refraction, as it is usually termed, is found to have undergone a physical change in passing through the crystal. Being made to fall upon another crystal, similarly situated, it is not subject to further division. If the axial planes be at right angles to each other, the ordinary and extraordinary rays change places. At intermediate situations there are four images. Rays thus physically changed are said to be *polarized.* Demonstrations of these facts by means of the polariscope.

285. The mineral Tourmaline. Its polarizing power. Its peculiar adaptation to the examination of rays polarized by other agency. Nicol's Prism. Illustrations by means of sectional models.

Experiments.

First. A plate of tourmaline is held between the eye and a candle; the light appears distinctly through it, and if the plate be turned round in the same plane no change is observable.

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* Appendix, Note X.

Second. A similar plate is interposed between the first plate and the eye, and is turned round; the light now appears and disappears, alternately, at every quarter revolution of the plate.

Third. A ray of light is divided by a crystal of Iceland spar. Examined by tourmaline, the ordinary and extraordinary ray found to have their maximum intensities at opposite points.

286. A ray of light reflected at a certain angle, varying for different substances, is found to have undergone a similar change. For polished glass the polarising angle is 56° 45′.

EXPERIMENTS.

First. A ray of light is made to fall upon a polished glass surface, at an angle of 56° 45′: the reflected ray is examined by a plate of tourmaline, and is found to possess the same properties as a polarized ray.

Second. A ray of light is reflected as in the last case, the reflected ray is received on another similar surface and at the same angle; the ray is reflected by, or passes through the glass, according as the second plane of reflection coincides with, or is at right angles to, the first.

287. Circular polarisation. Its nature and modes of production.

288. Analogy between the phenomena of sound and of light, suggested by the last experiment, established by Professor Wheatstone. Description of his experiment. Strong argument, in favour of the wave theory of light, supplied by this analogy.

289. A ray of polarized light, after traversing a thin plate of mica is, when examined by a plate of tourmaline, found to be brilliantly coloured. So also is such a ray after passing through a square prism of glass under pressure. In the position of the tourmaline in which the ray would, without the mica, disappear,

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* See Marbach's experiments, *Comptes Rendues*, *No.* 15, of 1855.

the tints are of singular brilliancy. The plate, turned round through a quadrant, exhibits tints which are complementary to the others, *i.e.* which, with them, produce white light. Demonstrations confirmatory of this by means of the polariscope. Grotesque figures made from thin plates of selenite, illuminated by polarised light, shown.

MAGNETISM OF LIGHT.

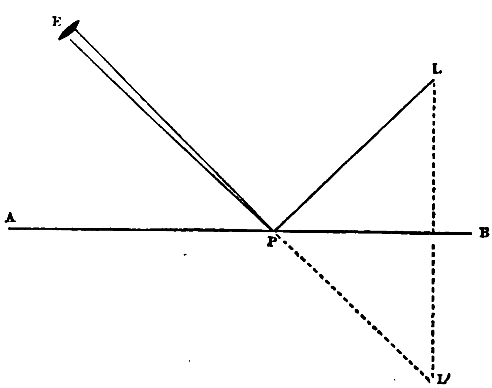
290. One of the most brilliant discoveries of modern times, is that of the magnetism of light, by Professor Faraday. He found that if a ray of polarised light be subjected to the action of a powerful magnet, it is made to revolve from right to left, or from left to right, according to the direction of the electric current. The rotation of this plane seems to be due to coercive force exerted by the magnet on the prism through which the light passes in the experiment.

CHAPTER XV.

OPTICAL INSTRUMENTS.

The Plane Mirror.

291. The most familiar of these, the plane mirror. Rays from every point of a radiating body, as for instance of the human face, fall on all points of a plane mirror. Only one image is seen. The physical law—"The angle of incidence is equal to the angle of reflection," prevents repetition and confusion. A curious illustration is this: Stand in front of a mirror, close one eye and place the finger over its image in the glass; then open the closed eye, and close the open one; the finger will still be seen over the closed eye.



Let L in the figure be a luminous point of an object, AB a section of the surface of a plane mirror by the plane of the paper; E the pupil of an eye viewing the image of L in the mirror. The image, in such cases, called virtual, will appear to be at L′ the same distance behind the mirror as the object itself before it. It is evident that rays of light falling parallel on the mirror, will leave it also parallel.

292. Convex and concave mirrors and their principal properties. Demonstrations.

Images formed by Lenses.

293. Different forms of lenses. Rays of light, traversing a convex lens, are deflected from their path towards the axis of the lens, and an image of the radiant is formed behind the lens. The focus of a lens. *Focal length,* what and how determined. Rays of light, traversing a concave lens, are deflected thereby from the axis, and owing to their dispersion no image of the radient is formed. If the convex surface be a reflecting one, an image will be formed in front of the mirror. Telescopes are of two kinds, refracting and reflecting Telescopes. Geometrical illustrations, and demonstrations, of the influence of different refracting and reflecting surfaces, in the formation of images.

The Telescope.

294. The interest attaching to the construction of this instrument. Its convenience and value to the traveller and mariner. Its inestimable importance to the astronomer. The revelations which he has been enabled to make by its aid, adverted to. Impassable limit, to which astronomical knowledgew as restricted, prior to the invention of the telescope. Of the numerous primary and secondary planets now known, only six, or at most seven of the former, and one of the latter, would have been known to man, without the agency of this admirable instrument. The rings of Saturn, the lesser comets, and a vast number of independent and associated stars, are classed amongst the discoveries due to the same agency. Galileo, the first to perceive the astronomical value of the invention of the telescope. His discovery of the Satellites of Jupiter.

Refracting Telescopes.

295. *The Telescope of Galileo.*—This telescope consisted of two lenses, convex and concave; the former being the object glass. The distance between the glasses was the difference of their focal lengths. He fixed them in a leaden tube, their coincident axes coinciding with the axis of the tube. The arrangement exhibited in diagram, and the mode of formation of an image of the radient, explained. Instead of the concave eye glass used by Galileo, a convex one might be used, the distance between the lenses being equal to the sum of the focal lengths of the glasses. The capability of such an arrangement for the formation of images, considered. Indistinctness manifests itself in an image formed by this arrangement, owing to the spherical excess and chromatic aberration. The nature of these, and their influence in embarrasing images explained. The chromatic object glass of Dolond.

296. *Astronomical Telescope.*—Instead of one eye-glass, two plano-convex ones are now used in astronomical telescopes. The virtue of this arrangement, in correcting the defects of single eye-glasses, considered. Inversion of objects by such telescopes.

297. *The Spy-glass.*—The telescopes used by mariners and others, for examining remote terrestrial objects, commonly known by this name. Such telescopes exhibit objects in their natural position. Manner in which this is effected, explained. Loss of light by absorption in such arrangements. The supplementary or reversing glasses being removed, leave an astronomical telescope —the night glass of mariners. Demonstrations.

The Reflecting Telescope.

298. In reflecting telescopes rays of light from the radiant are received upon a polished metallic mirror, placed at the bottom

of the telescopic tube, which serves as the object-glass in refracting telescopes. The mirror so formed as to give an image of the radient near the mouth of the tube, where it is received upon another mirror, or directly by a system of eye-glasses. Description of Herschel's Telescope. Lord Rosse's Telescope.

The Microscope.

299. The Microscope is an instrument for examining small objects, such as animalculæ, invisible to, or imperfectly seen by, the naked eye; or the minute structure of organic and inorganic bodies. Importance of the results arrived at by its agency. Ehrenberg's observations and discoveries. The simple microscope. The compound microscope.

The Camera Obscura and Camera Lucida.

300. The Cameras are instruments employed as aids in the delineation of figures, buildings, landscapes, &c. The Camera Obscura forms a picture upon a ground surface of glass, which may be copied at leisure. The Camera Lucida forms the image upon the drawing paper itself, which may then be traced.* The instruments exhibited and described, and the method of using them shown.

301. The Camera Obscura has of late years risen to considerable importance, through the invention of Photography. By this art the lights and shadows of the picture in the camera can be rendered permanent in a second of time. Processes for the taking of photographic pictures on collodion films and on paper. Specimens exhibited. The Daguereotype. The Calotype. Negative pictures. Positive pictures.†

* Appendix, Note Y.

† See a Manual of Photographic Chemistry, by T. F. Hardwick. Journal of the Photographic Society of London, passim.

Experiments.

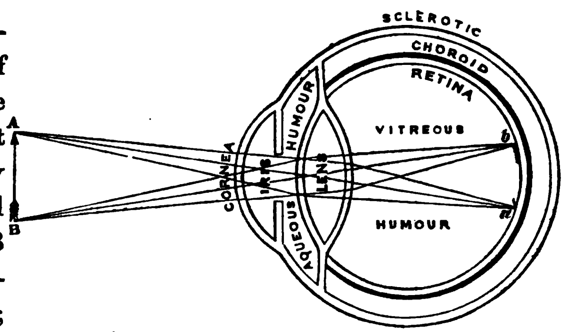
First. Chloride of silver is precipitated in two phials by addition of common salt to solution of nitrate of silver (lunar caustic); one is exposed to light, the other is excluded from it. In a few minutes the chloride in the light is blackened, while the other remains unchanged.

Second. A picture taken by the collodion process.

The Eye.

302. The most magnificent optical instruments are the eyes of animals,—varied in form, disposition, and power, according to the conditions under which they are to be used; displaying the infinite intelligence of their Maker. Demonstrations from diagrams, and a dissecting model of the human eye.

303. A sectional diagram of the eye is here given to assist those who may not have a model to consult; AB is an object viewed by the eye; AB its image on the retina.



Membranous Elements.

The Sclerotic.—The membraneous element, commonly termed the white of the eye.

The Cornea.—The transparent membrane, stretching over the pupil and iris, and constituting the front of the eye.

The Choroid.—The inner coating of the sclerotic, coloured black, and constituting a screen upon which external images of objects are formed.

The Retina.—A delicate net work, spread over the choroid, and formed by the expansion of the optic nerve.

The Pupil.—The central opening of the eye, protected by the cornea, through which rays from the radiant pass. The black pigment of the choroid appears through this opening, giving to it the appearance of an intensly black circular spot.

The Iris.—A thin circular membrane around the pupil, the function of which is to regulate the quantity of light admitted into the eye by enlarging or narrowing the opening.

REFRACTING ELEMENTS.

The Aqueous Humour.—The fluid anterior to the crystalline lens, and in which the iris floats. This fluid keeps the front of the eye distended; and thereby affords admission to oblique pencils of light.

The Crystalline Lens.—Is a double convex lens, and lies immediately behind the iris. It increases in density from the circumference to the centre, a contrivance by which the spherical aberration is corrected.

The Vitreous Humour.—A fluid occupying the posterior portion of the sclerotic cavity.

REFRACTING POWERS OF THE HUMOURS.

Aqueous humour	1·337
Crystalline lens (outer coat)	1·377
Ditto ditto (centre)	1·399
Vitreous humour	1·339

The Optic Nerve.—A nerve which, proceeding from the brain, enters the base of the eye, and spreads out into the retina.

304. If the eye be deranged, as by flattening of the lens through age, or if through too great convexity naturally, as in shortsighted persons, indistinct vision will be the result. In the former case the picture will be formed behind the retina; in the latter, before it. Demonstrations of this by experiment. Convex spectacles in the one case, and concave ones in the the other, respectively, assist the eye in re-adjusting the image. Illustrations of this.

Binocular Vision.

305. The perception of solidity depends on the superposition of the impressions derived simultaneously from a solid object through either eye. This fact was first made known by Professor Wheatstone. If a solid object placed at a distance from the eye, for instance a thin book or model of a crystal held at arm's length, be viewed with both eyes, then with one alone, then with the other, its appearance will be different in each case. If the experiment be performed in a room, the projections of the objects on the wall will be seen to occupy different positions; that of the object seen with both eyes together, in the middle; that with the right eye towards the left, and that seen with the left eye towards the right.

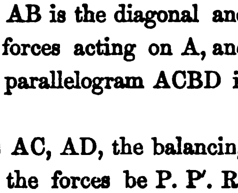
306. *The Stereoscope.*—Wheatstone's Stereoscope. Brewster's Stereoscope. Demonstrations. Stereoscopic Photographs, how taken.

307. *The Pseudoscope* (Wheatstone's). Its construction.

APPENDIX.

NOTE A.

If a point be at rest under the operation of n. forces, acting on it, in the same plane, they may be represented by a polygon of n. sides: since any two of the adjacent sides of the polygon may be represented by a line joining their extremities, and thus the polygon will be reduced to n—1 sides: continuing the operation it will be reduced ultimately to a triangle. Let ABC be the resultant triangle, in which A is a point acted on by the forces represented by the sides of the triangle. Draw AD parallel and equal to BC; since its magnitude and direction are the same as those of BC, it represents the same force as BC does; join BD; ACBD is a parallelogram of which AB is the diagonal and AC, AD adjacent sides: now AC, AD represent forces acting on A, and AB is their resultant or balancing force. The parallelogram ACBD is the parallelogram of forces of the text.



If the component forces act in the directions AC, AD, the balancing force will act in the opposite direction. Let the forces be P. P′. R′. then since in the case assumed

$$P+P'+R'=0$$
$$\therefore P+P'=-R'$$

The negative sign indicates that the direction of R′ is opposite to that of P+P′.

The three forces may be further reduced to two: for since AC, AD, are equivalent in effect to AB, we have, making $AB=R$

$$P+P'=-R'$$

$$\text{but } P+P'=R$$

$$\therefore R=-R'$$

This result is represented by the line $-R'$ A R'

$-R'$ A R

Examples to Chapter II.

1. Two forces of 8 and 10 seers, respectively, act in the same straight line on a point. What will be the magnitude of the resultant; first when the directions are the same; secondly, when the directions are opposed ?

2. Two forces of 12 and 20 seers act at right angles to each other on a point. What will be the magnitude and direction of their resultant ?

3. Two component forces, acting at right angles to one another, are respectively as 3 and 4. Show that the resultant force is represented by 5.

4. A point is acted upon by three forces of 7, 8, and 16 lbs. May the point be at rest ?

5. Prove that if two forces act upon a point at an angle less than two right angles, their resultant cannot be zero.

6. Find a point in a triangle such that, if straight lines be drawn from it to the angular points of the triangle, the forces represented by these lines will keep the point at rest.

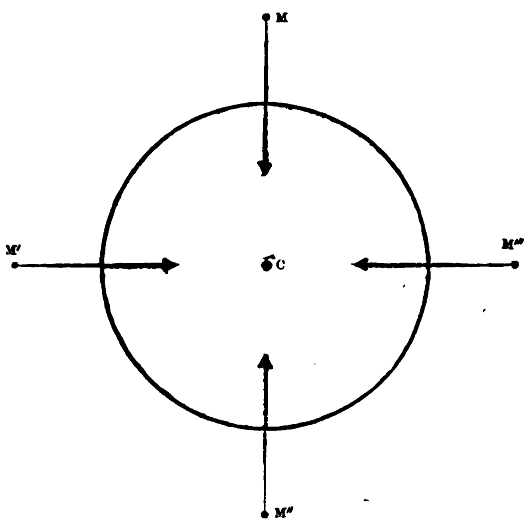
7. Three forces act perpendicularly to the sides of a triangle at their middle points, and are proportional to the sides; prove that they are in equilibrium.

8. A body of the weight of 20 seers moves with the velocity of 12 feet in a second; what is the numerical value of its moment ?

9. Which has the greater moment; a body of 12 seers weight moving with a velocity of 30 feet a second, or one of 20 seers moving with the velocity of 20 feet a second ?

10. A body has a mass of 8 seers, while that of another is 12 seers; the former moves with the velocity of 50 feet a second; with what velocity must the second move that the moments of both may be equal?

Note B.



Let the above circle represent a section of the earth through its centre C; M, M', M'', M''', masses near its surface. When free they by fall perpendicularly to the surface, and therefore all, if not arrested by the earth's solidity, would proceed towards the centre in the direction indicated by the dotted lines, or as a stone passes through water. The distances through which M, M', &c. fall in the unit of time may properly be taken as the unit of distance; so also may the velocity generated in that time be taken as the unit of the force by which it is produced, and of which it is therefore the measure. These quantities are, in the latitude of London, 16·08 feet and 32·16 feet respectively.

NOTE C.

The small weight used in the experiments, detailed in the text, was $\frac{1}{64}$ of the larger weights together with itself; so that the effect of gravity on the smaller weight, distributed throughout the mass of both the large weights and itself, can be only $\frac{1}{64}$ of its whole amount; the velocity of the system will therefore be but $\frac{1}{64}$ of the velocity of the small weight falling freely, while the character and laws of the motion will remain unaltered. Now it has been proved that bodies move through 16·08 feet in the first second of their fall, at the sea level and in vacuo; hence the space through which the system employed in these experiments would move must be $\frac{1}{64}$ part of this, or 3 inches nearly, agreeably to the fact.

If m be taken to represent the small weight, and M each of the large ones, then the whole mass moved during the experiment is $2\,M+m$. Now since the moments of the whole must be this same as that of the small weight, falling freely, we have, taking x to represent the velocity of the system,

$$x\,(2\,M+m)=m\,g$$

$$\therefore x = \frac{m}{2\,M+m} \cdot g$$

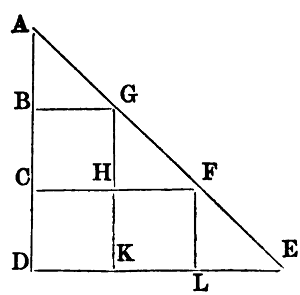
The number $\frac{m}{2\,M+m}$ is, in our experiment, $\frac{1}{64}$; we might have made it any other if convenience had so suggested.

The law $S=sT^2$ is known as Gallileo's law, having been first established by that philosopher: he performed his experiments upon falling bodies by means of an inclined plane.

NOTE D.

The laws of accelerated motion may be represented geometrically as follows:—

Let ADE be a right-angled triangle, and AB, BC, CD represent units of the time of fall of a descending body; then will BG, CF, DE represent the velocities acquired, and ABG, BF, CE the spaces described during those times.



We have AB : AC : AD : : BG : CF : DE

Inverting and substituting

$$V : V' : V'' : : T : T' : T''$$

Again—

$$BH = 2 \cdot ABG$$
$$2CL = 2 \cdot ACF$$

or

$$V = 2\,sT$$

also

$$ABG = ABG \cdot 1 = ABG \cdot 1^2$$
$$ACF = ABG \cdot 4 = ABG \cdot 2^2$$
$$ADE = ABG \cdot 9 = ABG \cdot 3^2$$

or $S = sT^2$

Finally

$$ABG : BF : CE : : 1 : 3 : 5$$

or $S : S' - S : S'' - S' : : 1 : 3 : 5$

Examples to Chapter III.

1. A heavy body is let fall from the top of a tower 160 feet high; in what time will it reach the bottom?

2. The data as in the last case; what will be the velocity half way down, and what at the end of the fall?

3. Through what space will a body falling freely, descend in $3\frac{1}{2}$ seconds?

4. A body is projected upwards with the velocity of 50 feet in a second; to what height will it ascend, and what distance will it have reached at the end of 4 seconds?

5. A body falls freely from a given height; it is required to divide the height into four such parts, that each may be described by the body in the same time.

6. If a body were projected upwards with sufficient force to carry it 1000 háts; what would be the velocity of projection?

7. The data being as in question 4th; required the velocity of the body, when half way down, on its return to the earth.

8. A body is projected downwards from a baloon, a mile above the earth, with a velocity of 12 feet in a second; what would be its velocity half way down, and what on reaching the ground, if the atmosphere offered no resistance?

9. A body rolls down a perfectly smooth plane, inclined to the horizon at an angle of 25° 30′. What will be the nature of the motion, and what the velocity of the body when it has moved through 150 feet?

10. How might a blind man furnish himself with data for determining the depth of a well?

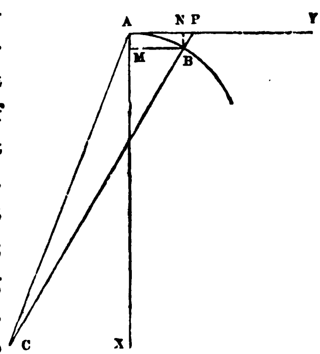
11. A stone dropped from the summit of a rock by the sea shore is heard to reach the water in 5 seconds of time. Required the height of the rock, the velocity of sound being 1130 feet in a second.

12. What is the length of a pendulum which vibrates seconds in the latitude of London, and at the sea level, g being 32·16 feet?

13. Which will vibrate faster, a pendulum at the equator or one of the same length at the poles, and why?

14. A pendulum, which vibrates second at the sea level, is found to lose five vibrations during 24 hours, on the top of a hill; required the height of the hill.

Note E.



The following demonstrations on central forces are taken, with some alteration, from 'Weisbach's Mechanics.' Let AB be a very small arc of an orbit of which C is the centre of curvature; it may be considered as a straight line. Let AM, AN be the resolved parts of AB in the direction of the axes of X and Y; *i.e.* in the direction of the accelerating force, and of a tangent to the curve. Now since AB is very small, AP is also

very small, and hence they may be considered equal to one another; also NB=AM. Hence BP=AM (BN) sin $a=\frac{pt^2}{2}$ sin a (t being the very small portion of time in which AB is described), and NP$=\frac{pt^2}{2}$ cos a. Again AN$=ct$ (c being the velocity at A, in the direction AY); hence AP$=ct+\frac{pt^2}{2}$ cos a.

Again $AP^2=BP\ (BP+2\ BC)=2\ BP\ r$ nearly, since BP is very small compared to 2 BC; hence we have

$$CA=CB=r=\frac{AP^2}{2\ BP}=\frac{\overline{ct|}^2}{pt^2 \sin a}=\frac{c^2}{p. \sin a}$$

If the direction of the central forces coincide with the radius of curvature $a=90°$ and

$$r=\frac{c^2}{p}\ ;\ p=\frac{c^2}{r}$$

For any mass $M=\frac{W}{g}$ the power will be

$$Mp=\frac{Mc^2}{r}=\frac{Wc^2}{gr}$$

and for a velocity v

$$Mp=\frac{Wv^2}{gr}$$

or $$P=\frac{Wv^2}{gr}$$

$$\therefore P : W :: 2. \frac{v^2}{2g} \quad : \quad r$$

$$:: 2s \quad : \quad r$$

Thus we find that, *the centrifugal force is to the weight of the body, as the space due to the velocity is to the radius of the orbit.*

If the motion be uniform, we have

$$P=\frac{Mc^2}{r}=c^2.\frac{M}{r}=\left(\frac{2\pi r}{T}\right)^2.\frac{M}{r}=\frac{4\ \pi^2}{T^2}.\ Mr=\frac{4\ \pi^2}{g}.\ \frac{Wr}{T^2}=1{\cdot}224\frac{Wr}{T^2}$$

If, instead of T, we substitute the nnmber of revolutions per minute, or $T=\frac{60}{n}$ we obtain

$$P=\frac{39{\cdot}4784}{3600}\,n^2\,Mr=0{\cdot}010966\,n^2\,Mr=0{\cdot}000331\,n^2\,Wr$$

Finally, if we put w for the angular velocity $\frac{2\pi}{T}$ we get

$$P=w^2\,Mr$$

Most of the laws of centrifugal force, deduced from experiment, will be recognized in the above equations.

Examples to Chapter IV.

1. If a body of 20lbs describe a circle of 4 feet radius 400 times a minute, what will be its centrifugal force ?

2. Which has the greatest centrifugal force, a body of 12 lbs. weight moving in a circle of 8 feet radius; or one of 15 lbs. describing a circle of 2·5 feet radius, the times of revolution being the same ?

3. While a mass of 28 seers is describing a circle of 20 feet radius, eighty times in a minute, what is the least force, and in what direction applied, which will bring it to a state of rest ?

4. A stone, weighing $\frac{1}{10}$th of a seer, is swung round by a sling, the string of which is $2\frac{1}{2}$ feet in length. What will be the tension on the hand of the slinger, if the stone be swung round twice in a second ?

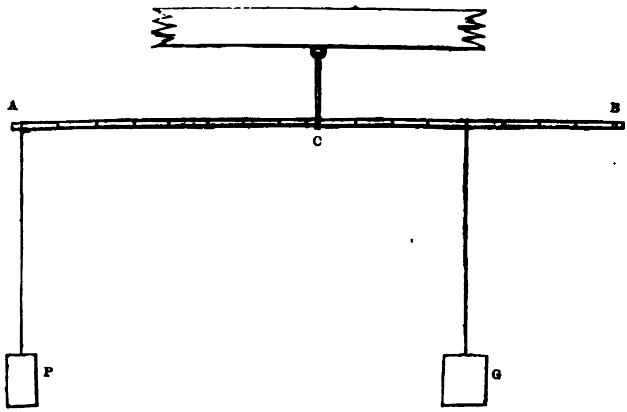
5. The equatorial radius of the earth being 3968 miles, and the time of revolution 24 hours; how much is the weight of a body lessened at the equator by centrifugal force ?

6. If the day were $\frac{1}{17}$ of what it is, or about $1\frac{1}{2}$ hours long, what would be the weight of bodies at the equator ?

7. The mean siderial period of Jupiter is 4332·585, and of the earth 365·256 of our days; and the distance of the earth from the Sun is 95,000,000 of miles. What is the distance of Jupiter from the Sun ?

8. The distance of Neptune from the Sun is 33·06 times the distance of the earth from the Sun. What is the length of his year ?

Note F.



Let P Q be weights, 4 and 8lbs. respectively, AB a rod divided into equal parts from C towards A, and from C towards B; then if P be suspended at the eighth division towards A, it may be shown that when Q is suspended at the fourth division, on the other side of C, there will be equilibrium; but that there will not be equilibrium if Q be suspended at any other point.

Any number of forces similarly related as the above, in respect of magnitude and situation, would obviously balance each other about C. When such forces are weights, the point about which they balance is termed the centre of gravity.

Note G.

The following principle may be adopted in the solution of examples 5 and 6 of the following exercises.

When a body is retained in a circular orbit, by a force acting towards the centre, its velocity at any point is equal to what it would acquire, by falling freely through half the radius of its orbit.

EXAMPLES TO CHAPTER V.

1. Where will the centre of gravity of a homogeneous rod, 6 feet long, lie?

2. A rod of 4 feet long, the weight of which is neglected, is loaded at each end with weights, one being 12 and the other 18 seers. At what distance from the greater weight will the centre of gravity lie?

3. A rod of 12 feet long, the weight being neglected, is loaded with weights of 8, 10, 7, and 16 seers, at distances 1, 4, 8, and 10 feet respectively, from one extremity. At what distance from the same extremity will the centre of gravity lie?

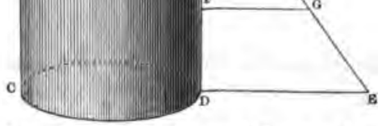
4. The mass of the earth to that of the moon being as 100 : 1·252, at what point in a line, joining the centres of the two bodies, will the centre of gravity of the system lie?

5. Find the greatest speed at which a man 6 feet high may walk.

6. A person 5·5 feet high walks upon stilts, which add 5 feet to the length of his legs, and lower his centre of gravity half a foot. What is the maximum speed at which he will be able to walk?

NOTE H.

Let A B C D be a vessel filled with some liquid, as water, up to A B. The pressure at the surface will be O, while at the bottom it will be a maximum. Further, the whole mass of liquid may be viewed, in this case of a cylindrical vessel, as made up of a number of circular discs of the liquid, of equal thickness, and hence of equal weights; the pressure at any point, in the side of the vessel, will be therefore as the number of discs above that point, *i.e.* as the depth of the liquid to that point.



Describe the right-angled triangle BDE, take any point F in BD, and draw FG parallel to DE; the pressure at F is as BF and at D as BD; but BF : BD : : FG : DE; hence FG and DE represent the pressures.

Again; the triangle BDE is made up of lines FG parallel to the base, hence the triangle represents the total lateral pressure, and the centre of gravity of the triangle, the centre of pressure; but the centre of gravity of the triangle is situated at one-third the height of the triangle from the base; therefore the centre of lateral pressure is also situated at one-third the height of the vessel from the base. For different forms of surface of pressure see Golding Bird, and Brook's Natural Philosophy, 4th Ed. p. 185.

NOTE I.

SPECIFIC GRAVITIES.

1. In the case of a body heavier than the liquid of comparison.

Let d be the density to be found,

d' .... of the liquid.

W, the weight in air, of the body, the specific gravity of which is to be determined.

W′, its weight in the liquid.

P, the pressure upward of the liquid=the pressure downward of the body=the weight of the fluid displaced.

The mass of fluid displaced=the volume immersed, and its weight is

$$P = Vd'g$$
$$W = Vdg$$

Hence $$\frac{d}{d'} = \frac{W}{P} = \frac{W}{W - W'}$$

$$\therefore d = \frac{W}{W - W'} . d'$$

But the specifie gravities are easily seen to be as the densities; hence,

$$S = \frac{W}{W - W'} . S' \qquad \text{(A)}$$

2. In the case of a body lighter than the liquid; attach a body to it, sufficiently heavy to make it sink, then proceed as follows. Find W, the weight in air, of the body to be weighed.

w, w', the weights in air and the liquid, respectively, of the sinker,

W′, the weight of both in the liquid,

then $W + w = W''$ is the sum of the weights of both in air.

$w - w' = l$, the loss of the sinker in the liquid.

$$\therefore S = \frac{W}{W'' - (W' + l)} . S' \qquad (B)$$

3. A body in powder, but insoluble in a given liquid.

First. Weigh a portion of the substance in air, and let its weight as before $= W$.

Second. Determine the weight of a specific gravity bottle and its contained liquid, and let it $= W'$.

Third. Introduce the powder into the bottle and weigh. Let the weight $= W''$.

Since the difference, between $W + W'$ and W'', can only be due to the liquid which has been displaced by the substance, *i.e.* to the volume of the substance; we have:—

$$S = \frac{W}{W + W' - W''} . S' \qquad (C)$$

4. Determination of the specific gravities of liquids.

First. By means of a solid of known weight.

Weigh first in the liquid the specific gravity of which is required, and then in the standard liquid.

Let l = the loss in the one

l' = „ „ other

S, S' = their specific gravities respectively.

The losses will be as the resistance of the fluids, *i.e.* as their densities, which are as their specific gravities; hence

$$l : l' :: S : S'$$

$$\therefore S = \frac{l}{l'} . S' \qquad (D)$$

Second. By the Hydrometer.

Let V be the volume of the instrument.

v . . . . of a degree of the stem.

Let the hydrometer be floated in two liquids whose specific gravities are S, S'; and let the number of degrees of the stem above the surfaces of the liquids be n, n' respectively. The volumes of the stem above the liquids will be $nv, n'v$.

The volume immersed in either case will be:—

$$V - nv$$

$$V - n'v$$

which is equal to the volume of fluid displaced.

The weights of the liquids displaced will be:—

$$(V - nv)\ S = W$$
$$(V - n'v)\ S' = W'$$

Now the weights are the same in either case, being equal to the weight of the hydrometer.

Hence $$\frac{S}{S'} = \frac{V - n'v}{V - nv}$$

$$\therefore S = \frac{V - n'v}{V - nv} . S'$$

If v be the unit of volume of the hydrometer, V becomes Nv and therefore:—

$$S = \frac{N - n'}{N - n} . S' \qquad \text{(E)}$$

Cor. If in the above cases d' be taken as the unit of density,—as distilled water, at the temperature of 62° of Fahrenheit, and an atmospheric pressure equal to 30 inches of mercury, generally is,—S′ will be the unit of specific gravity, and the above equations will become

$$\text{(A)} \qquad S = \frac{W}{W - W'}$$

$$\text{(B)} \qquad S = \frac{W}{W'' - (W' + l)}$$

$$\text{(C)} \qquad S = \frac{W}{W + W' - W''}$$

$$\text{(D)} \qquad S = \frac{l}{l'}$$

$$\text{(E)} \qquad S = \frac{N - n'}{N - n}$$

Note. The following formulæ are also convenient in practice:—

Let P = the total pressure of a liquid.
s = the surface of pressure.
h = the height.
d = the density.
w = the unit of weight.

Then for the same surface we have in case of equilibrium, and since

$$P = s\,h\,w\,d$$
$$s\,h\,w\,d = s\,h'\,w\,d'$$
$$\therefore \frac{h}{h'} = \frac{d'}{d}$$

Examples to Chapter VI.

1. The diameter of the bottom of a cylindrical vessel is 3 feet, and its height is 8 feet. What is the pressure on the bottom of the vessel, when it is filled with water?

2. A vessel 3 feet deep, and wider at the mouth than at the bottom, is of the form of a truncated cone; the interior diameters of the ends being 8 inches and 11 inches, respectively. What will be the pressure on the bottom, when the vessel is filled with mercury.

3. Water and oil of turpentine balance each other in a syphon tube; the height of the column of water is 15·375 inches; what is the height of the column of turpentine, its specific gravity being 0·78?

4. A column of mercury 30 inches in height rests upon a surface. What pressure does the surface sustain, the specific gravity of mercury being 13·568?

5. What height of column of water and of air, of uniform density, would the column of mercury of the last example support in a syphon tube, water being the standard, and the specific gravity of air being 0·0012?

6. The interior diameter of a hydrostatic bellows is 2 feet; the sectional area of the tube 1 square inch, and its height 6 feet. What weight may be raised by the bellows; first, by means of water; second, by means of mercury, specific gravity 13·0; and third, by means of alcohol, specific gravity ·84?

7. What pressure do creatures inhabiting the sea at the depth of 1000 feet sustain? If a weight of the same amount were placed upon them at the earth's surface, would they be able to endure it?

8. A piece of platinum weighs 254·56 grains in air, and 242·5 grains in water; required the specific gravity of platinum.

9. A piece of silver weighs 432·75 grains in air, and 391·54 grains in water; required the specific gravity of silver.

10. From the data of the last two questions, what is the relation, for equal weights, between the volumes of the platinum and silver?

11. A piece of Bhurtpore sandstone is found to weigh, in air, 836·5

grains, and in water, 483·48 grains. What is the specific gravity of the stone?

12. A portion of the sandstone, of which the Quotub Minar at Delhi is built, weighs in air 1891·3 grains, and in water 1076·45 grains; a piece of the black limestone of the Soan weighs in air 1069·5 grains, in water 675·58 grains. Compare the densities of the two stones.

13. A piece of cork weighs 68·45 grains in air; it is attached to the silver of the ninth question, and both together are found to weigh, in water, 5·25 grains. What is the specific gravity of cork?

14. Wishing to determine the specific gravity of a powder, not soluble in water, I made the following weighings:—

Powder - - - - - - - -	64·15	grains.
Specific gravity bottle filled with water -	1636·7	"
The same bottle filled with the powder and water together - - - - -	1674·25	"

Required the specific gravity of the powder?

15. A sphere of silver is to be coined into rupees, $\frac{1}{7}$th of alloy having first to be added; the diameter of the sphere is 8 inches, the specific gravity of silver being 10·5, and a rupee weighing 180 grains. How many coins will be produced from the sphere?

16. A hydrometer, the stem of which is graduated to thousandths of its volume, is made to float in two liquids; in the one 60 degrees, and in the other 90 degrees of the stem are above water. What are the relative densities of the liquids?

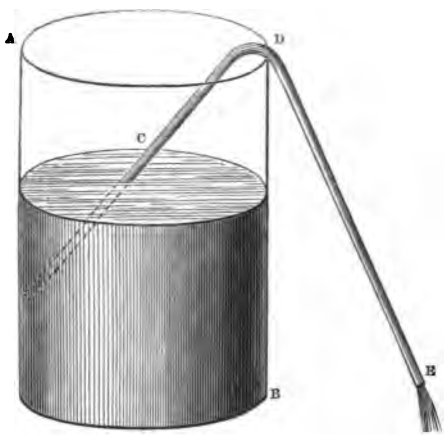
17. A hydrometer, graduated from the extremity of its stem, into ten thousandths of the volume of the instrument, has its zero point determined for distilled water; when floated in a certain liquid, 600 degrees of its stem rise above the surface. What is the specific gravity of the liquid?

18. Into how many cubic inches of steam are 5·5 cubic inches of water convertible?

19. Water was found to boil, on the top of a hill, at 208·25° of Fahrenheit; required the height of the hill?

20. At what temperature would water boil on the summit of Dawalagiri, the height being 27,000 feet?

Note K.



Let AB be a jar containing liquid; CDE a syphon, with one limb DC immersed, and the other, DE, free. Suppose the syphon to be filled with the liquid; D a disc of the same by parallel sections, perpendicular to the axis of the syphon, at the highest point; the motion or rest of D is dependent on the forces acting upon it, along the limbs of the syphon.

Since the surface of the liquid is subject to the pressure of the atmosphere, *i.e.* to about 15 lbs. on every square inch of surface, and since fluids transmit forces applied at any one point of their mass to every other point, the pressure on the immersed orifice of the syphon, and hence up its limb, is at that rate; but since the tube is of uniform bore, and the difference of the length of the limbs small, the pressure at E is equal to the pressure at C,—equal to P. Again; the forces, acting up the limps, CD, ED, upon the disc D, are opposed by the forces Vdg and $V'dg$ respectively, where V, V' is the volume of liquid in either limb; let these forces be represented by p, p'. Hence the total force upon D, in the direction CD, is $P-p$; while $P-p'$ is the force, acting on it in the direction DE.

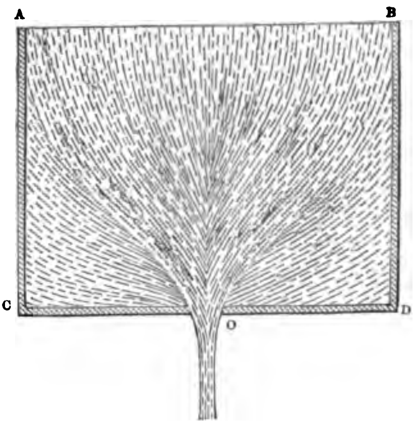
Now, if $p > p'$, which it is when E is at a higher level than C, $P-p < P-p'$, and D will move down the limb DC; for this condition, therefore, the liquid will flow back into the vessel.

If $p = p'$, which it is when the levels of E and C are identical, $P-p=P-p'$, and D will be at rest; in this case the liquid will flow neither way.

If $p < p'$, which it is when E is at a lower level than C, $P-p > P-p'$, and the disc D will be urged down the limb DE; the liquid in

this case will flow out through the syphon. This then is the condition of action of the syphon, *that the orifice of the outer limb be maintained at a lower level than the surface of the liquid being removed.*

Note L.



Let AD be a vessel having a funnel-shaped orifice, O, in its bottom. If the liquid be allowed to issue out at this orifice from the full vessel, the latter will become emptied above, the intermediate part remaining as before; the liquid discharged must be considered, therefore, to come from the surface. Let us however consider the vessel to be kept full during the discharge, and let Q be the discharge in the unit of time, and d the density of the liquid; then the mechanical effect of Q, in moving through h, will have been dQh; but the effect of the same mass, due to the velocity from O is $\frac{v^2}{2g}$; and the effects being identical, we have

$$dQh = dQ\frac{v^2}{2g}$$

$$\therefore v = \sqrt{2gh} = 8{\cdot}03\sqrt{h}$$

This result gives us the law enunciated in the text, and which is due to Torricelli.

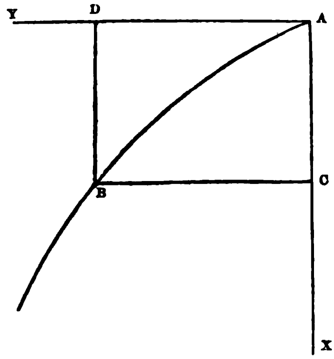
A slight retardation is found, in practice, to arise probably from the interference of lateral currents, which gives, according to Weisbach, a co-efficient of about ·97; hence the equation

$$v = 8{\cdot}03\sqrt{h}$$

becomes

$$v = {\cdot}97 \times 8{\cdot}03\sqrt{h}$$
$$= 7{\cdot}79\sqrt{h}$$

Note M.



Let AX, AY be co-ordinates at A, the commencement of the jet; B a point in the jet whose co-ordinates are AD, AC or x, y. If the jet were not deflected by gravity, it would proceed in the direction AY, with the velocity of projection; hence

$$y = ct$$

It is however acted upon by gravity, under the operation of which alone it would descend along AX; and in the time t, the space which it would describe would be

$$x = \frac{g}{2} t^2$$

Substituting for t, we get

$$x = \frac{g}{2} \frac{y^2}{c^2}$$

or

$$y^2 = \frac{2c^2}{g} x$$

which is the equation to the parabola, where

$$\frac{2c^2}{g} = 4a$$

Examples to Chapter VII.

1. What will be the working limit of a sucking pump, when the barometer stands at 28·5 inches?

2. What would be the working limit of a pump, at the top of a mountain; where the minimum height of the barometeric column is 22·48 inches?

3. Water is to be raised from a depth of 90 feet, by means of a lifting pump. What will be the length of the discharge tube, and what the tension at its lowest extremity? What would they be if the pump were a forcing one?

4. What quantity of water may be raised, in a day of 12 hours, by a pump of 6 feet stroke; the diameter of the cylinder being 18·57 inches, and the rate of working 8 strokes a minute?

5. What would be the limit of efficiency of a pump for raising alcohol, specific gravity ·839; and sea water, specific gravity 1·028, respectively, the lower limit of barometric range being 28·05 inches?

6. Water is thrown upwards, by a fire-engine, with the velocity of 50 feet in a second; to what height will it rise?

7. Water flows from a conical shaped orifice, in the bottom of a vessel 8 feet deep. What is the velocity of discharge of the water?

8. A fountain is supplied by a reservoir 20 feet above it; to what height should it play, theoretically, and what causes will modify that value?

9. Water issues from a horizontal jet, 12 feet from the ground, in the side of a cylindrical vessel, with a velocity of 6 feet in a second. At what distance from the bottom of the vessel will the jet reach the earth?

Note N.

Comparative Masses of the Atmosphere and Earth.

Let d be the mean density of the earth, M its mass, r its radius, and d' the density of mercury. We have for the earth's mass

$$M' = \tfrac{1}{3}\, d\, S\, r$$

$$\text{Hence } \frac{M}{M'} = \frac{d'\, S \times 2{\cdot}5}{\tfrac{1}{3}\, d\, S\, r}$$

$$\text{and } \quad M = \frac{d'\, S \times 7{\cdot}5}{d\, S\, r} M'$$

Let $r = 3968$ miles; $d' = 13{\cdot}6$; $d = 5{\cdot}5$, (which they are pretty accurately,) and we obtain

$$M = {\cdot}0000008892\ M'$$

or the mass of the atmosphere is nearly a millionth part of that of the earth.*

---

* Poisson, Traite de Mechanique.

Note O.

The Limit which the Atmosphere does not exceed.

The centrifugal force at the equator $= \dfrac{g}{289}$

At the distance z it is $= \dfrac{g\,(r + z)}{289\,r}$

Gravity at that distance $= \dfrac{g\,r^2}{(r + z)^2}$

Hence, for the limit, $\dfrac{g\,(r + z)}{289\,r} = \dfrac{g\,r^2}{(r + z)^2}$

The solution of this equation gives

$$z = r\,\sqrt[3]{289} - r = r\,(\sqrt[3]{289} - 1) = 5\,r \text{ nearly.}$$

Hence the limit adverted to does not exceed five times the radius of the earth.*

Examples to Chapter IX.

1. How much, by weight, of atmospheric air, will be contained in a vessel of $1\frac{1}{2}$ cubic héts; at mean pressure, and at the sea level?

2. How much, by weight, would the vessel of the last experiment contain at a height above the sea level of $1\frac{1}{2}$ miles?

3. If the atmosphere were of the same density throughout, and $8\frac{1}{2}$ miles high; what would be the mean height of the barometric column?

4. What would be the height of the barometric column, at a depth in the sea of 25 feet?

5. The height of the barometric column in a diving bell being 42·5 inches, required the depth,—a barometer at the surface standing at 29·5 inches?

The radius of two associate Magdeburg hemispheres is 3 inches. If the air be totally withdrawn from them what force will be required to separate them; first, when the barometer stands at 30 inches; second, when it stands at 28·5 inches?

7. Gay Lussac found, at the height to which he ascended in a balloon, the barometric column to be 12·3. What height above the sea does this give, by Leslie's formula, taking the mean pressure at the sea level to be 29·85?

* Poisson. Traite de Mechanique.

8. The height of Dewalgiri being 27,000 feet; what would be the height of the barometric column at its top, supposing the temperature to be 8·5° Fahrenheit?

Note P.

Table of the specific gravity and volume of water for each degree centigrade, from 0° to 30°, the unit being taken at the temperature of greatest density = + 4° C.*

Temperature.	Specific Gravity.	Volume.
0°	0·9998918	1·0001082
1	0·9999382	1·0000617
2	0·9999417	1·0000281
3	0·9999920	1·0000078
4	1·	1·
5	0·9999950	1·0000050
6	0·9999772	1·0000226
7	0·9999472	1·0000527
8	0·9999044	1·0000954
9	0·9998497	1·0001501
10	0·9997825	1·0002200
11	0·9997030	1·0002970
12	0·9996117	1·0003888
13	0·9995080	1·0004924
14	0·9993922	1·0006081
15	0·9992647	1·0007357
16	0·9991260	1·0008747
17	0·9989752	1·0010259
18	0·9988125	1·0011888
19	0·9986387	1·0013631
20	0·9984534	1·0015491
21	0·9982570	1·0017560
22	0·9980489	1·0019549
23	0·9978300	1·0021746
24	0·9976000	1·0024058
25	0·9973587	1·0026483
26	0·9971070	1·0029016
27	0·9968439	1·0031662
28	0·9965704	1·0034414
29	0·9962864	1·0037274
30	0·9959917	1·0040245

* Berzelius, Lehrbuch der Chemie.

NOTE.—The table shows that the density of water diminishes more rapidly than its specific gravity does. Now since by the expansion of bodies their capacity for heat is increased, this difference would seem to indicate weight, and hence materiality, in heat.

NOTE Q.

Let v, v' be the volumes, before and after dilation, of a rectangular bar.

l, l' the lengths before and after expansion.

Then, from the similarity of masses, we have:—

$$v' : v :: l'^3 : l^3$$

$$\text{and } v'-v : v :: l'^3-l^3 : l^3$$

Hence

$$\frac{v'-v}{v} = \frac{l'^3-l^3}{l^3}$$

$$= \frac{(l^2 + ll' + l'^2)(l'-l)}{l^3}$$

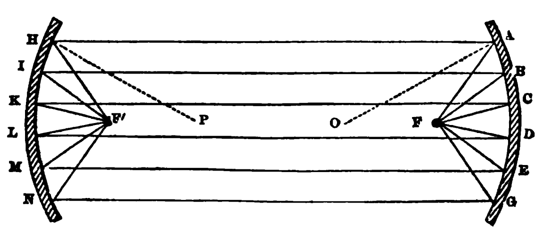
$$= \frac{3l^2 (l'-l)}{l^3}, \text{ ultimately}$$

$$= \frac{3 (l'-l)}{l}$$

$$\therefore v'-v = \frac{3 (l'-l)}{l} . v$$

The increase of volume varies therefore as the linear expansion.

NOTE R.



Let A ... G, H ... N be sections through the foci F, F′ of two parabolic mirrors placed opposite to, and at some distance from, each other;

let the heated ball be in F, and the bulb of the thermometer in F′. Since the rays of heat proceed from F in all directions, some of them will fall upon the surface of which A ... G is a section; let FA, FB, &c. be such rays. Now it is found that instantly the heated ball is placed in F, the thermometer in F′ is affected; it is found, moreover, that the disturbance is not due to the direct rays, since the thermometer may be placed much nearer to F′ than F is, without sensible effect being produced; it must therefore be due to the reflected rays. Now if rays proceeding from the focus, and reflected from the surface of one parabolic mirror be found in the focus of another placed opposite to it, they must have been reflected from the surface of the latter also; they must, moreover, have fallen upon it in a direction parallel to the common axis, or principal diameter, of the surfaces. Now from the nature of the parabola the angles made by FA, AH; AH, HF′ with the tangents at A and H, that is with the surfaces themselves at those points, are equal to another. Draw AO, HP normals to the surfaces at A and H: it is easily seen that FAO, OAH; AHP, PHF′ are equal to one another, and these are the angles of incidence and reflection: thus the law is established.

Examples to Chapter X.

1. What is the equivalent of 76° of Fahrenheit on the scales of Reaumur and Celsius, respectively?

2. The temperature of greatest density of water is, by the thermometer of Celsius, about 4°; what is it by those of Fahrenheit, and of Reaumur?

3. If mercury freezes at—40° on the scale of Fahrenheit; what is its freezing point on the scale of Celsius?

4. Suppose the mean temperature at the mouth of an artesian well to be 65° of Fahrenheit, and the heat to increase 1° for every 60 feet of depth, as it appears to do; at what depth would mercury boil and silver melt, the points for both being 600° and 1820° respectively?

5. A cylindrical bar of metal, 3 inches in diameter and 18 feet long, is found, under the operation of heat, to have gained an inch and a half in length. What will it have gained in volume?

6. A piece of platinum weighing 6 oz. is heated to the boiling point of water; it is then plunged into 3 ounces of water, of the temperature 59° of Fahrenheit, and is found to raise the temperature of the water to 68°, by its own cooling. What is the specific heat of platinum?

5. A pound of quicksilver at 40° is mixed with a pound of water at 156°; the resulting temperature is 152·3°. What is the specific heat of quicksilver?

Note S.

The positive and negative relation of metals differs with the nature and condition of the electrolite, and consequently with its action on each, as seen in the following table given by Becquerel;* in which, as in the text, every metal is positive to all that follow it.

Concentrated Nitric Acid.	Dilute Nitric Acid.
Oxidized Iron.	Silver.
Silver.	Copper.
Mercury.	Oxidized Iron.
Lead.	Iron.
Copper.	Lead.
Iron.	Mercury.
Zinc.	Tin.
Tin.	Zinc.

Note T.

It has been thought advisable to give here, briefly, an account of some of Volta's fundamental experiments, and the conclusions which he based upon them, since students find considerable difficulty in forming precise theoretical notions on this subject.

He employed, in the first experiment, two insulated metallic discs, one of copper, and one of zinc; and in the other a compound plate, made up of a plate of zinc and one of copper soldered end to end: in all, an electric condenser,—an Electrophorus with a small lid.

* Eléments D'électro Chimie.

Experiments.

First. He brought two insulated plates, one of copper and one ot zinc, into contact; and on separating them found the zinc positively, the copper negatively electric.

Second. Taking the compound plate, or pair, by the zinc end, he brought the copper end into contact with the copper plate of an electric condenser. On removing it, the condenser was found to be charged.

Third. Taking the compound plate by the copper end, he applied the zinc end to the plate of the condenser. On removing it, the condenser was found not to be charged.

Fourth. The same experiment as the first, but with a piece of moist paper interposed between the compound plate and the plate of the condenser. The condenser was now found to be charged positively.

Fifth. The second experiment, but modified as in the last case. The condenser was found to be charged negatively.

His explanation of the results are: metals, probably all bodies, exercise a reciprocal action, upon their respective electricities, when in contact. In the second experiment, the plate being held by the copper end, a portion of its electricity flows to the zinc end, when the latter is brought into contact with the plate of the condenser, the plate strives with equal force to discharge its electricity, and consequenthly none is communicated to it by the plate. In the third experiment, the copper end being brought into contact with the same metal, a portion of its electricity is transmitted, sufficient to establish equilibrium between the two.

In the fourth experiment, metallic contact between the plate and condenser being destroyed by the moist paper interposed, the electromoter force ceases, and hence the positive electricity of the zinc obtains admission into the condenser, charging it positively. The fifth experiment does not require particular explanation, but serves to throw light upon the rest, and is otherwise instructive.

The principle of action of the Voltaic pile, and the increase of power, with increase of the number of elements, in Voltaic batteries, become thus easily explained.

Let the pile be insulated, and let the electricity of a piece of zinc above that of a piece of copper, of the same size, be represented by unity.

Then, if the pile be composed of a simple pair, and if the electricity of the copper, considered as placed below, be represented by $-\frac{1}{2}$, that of the zinc will be $+\frac{1}{2}$.

If we now super-impose a piece of moist paper, or cloth, and then another piece of copper, the zinc and the copper first added will be equally charged; and, since the pile is insulated, the copper must have derived its charge from below. The state of the pile will now be—

The lowest plate	$-\frac{2}{3}$
The second	$-\frac{2}{3}+1=+\frac{1}{3}$
The upper	$=+\frac{1}{3}$

If, further, we now add a piece of zinc, it will, by the hypothesis, have a unit of electricity more than the copper with which it is in contact, and which—the whole being insulated—it can only obtain at the expense of those below. We shall thus have for the present condition of the pile—

The lowest plate	$-\frac{2}{3}-\frac{1}{3}=-1$
The second	$+\frac{1}{3}-\frac{1}{3}=\ \ 0$
The third	$+\frac{1}{3}-\frac{1}{3}=\ \ 0$
The upper	$0+1=+1$

Continuing in the same manner, for every additional pair, we shall have two arithmetic series, commencing at the middle of the pile, one ascending, the other descending, the sum of both together being equal to 0.

The conditions of the uninsulated pile are obtained similarly. In this case however, the earth being the reservoir from which the electricity is derived, the power of the pile is limited only by the number of pairs, as the following considerations will show.

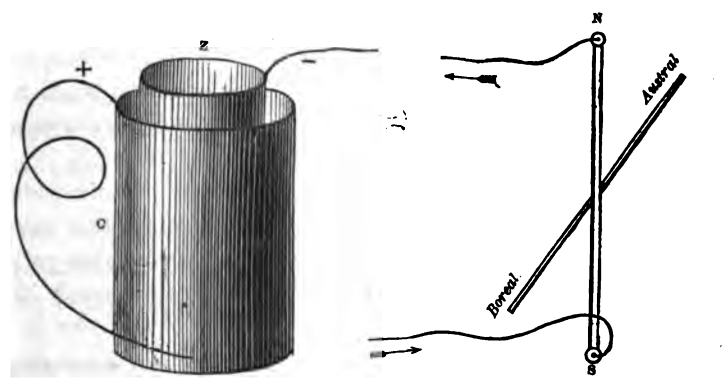
The electric excess in the lowest copper plate will be 0, since what is generated there by the electromotor force in the pair, will pass off into the earth. The electricity of the first zinc plate will therefore be 1. If a piece of moist paper or cloth, and then a copper plate, be super-imposed, the electricity of the copper will be the same as that of the zinc, viz. 1. If a piece of zinc be now placed upon the copper, its electricity will be the same as that of the copper + 1, *i.e.* 2; and so for any number of pairs. We thus have for successive charges of the zinc plates, beginning at the bottom.

First plate	1
Second	2
Third	3
Nth.	n

NOTE. The chemical theory has been purposely excluded from consideration, as being likely to perplex and embarrass the understanding of the pupil rather than assist it. There can be little objection to the exclusion, however, since either theory must be looked upon as only provisional,—the occasions, not the causes, of electric development being as yet certainly known.

NOTE U.

The following diagram will assist the student in comprehending the direction of rotation of a magnetic needle under influence of an electric current.



C, Z. The copper and zinc cells of a voltaic pair, respectively.

S N. The upper wire of the rectangle in the ordinary arrangement for Oersted's experiment; and situated in the magnetic meridian, according to the letters.

While the current passes, as in the figure, the needle will continue deflected towards the right, at its austral end; or, as we might express it, towards the east. If the current be reversed the same end will be deflected towards the west.

Note V.

Roemer and Cassini discovered, in the eclipses of Jupiter's Satellites, a measure of the velocity of light. That planet, lighted, like the others, by the Sun, casts behind it a conical shadow, into which when its Satellites fall, they become eclipsed, and thus invisible to observers on the Earth. Suppose the Earth in that part of her orbit lying between Jupiter and the Sun, when an eclipse of Jupiter's first Satellite takes place; then in $42^{h.}\ 28'\ 38''$ the same Satellite will be again eclipsed, and, if light had not progressive motion, the eclipses would be seen to recur at the end of every $42^{h.}\ 28'\ 38''$ from the first eclipse, without reference to the proximity or remoteness of the observer. When, however, the Earth is in that point of her orbit in which she has the Sun between her and Jupiter, and therefore the latter more distant from her than before by the diameter of her own orbit, the eclipses of the first Satellite are found not to recur at the computed periods, but about 16½ minutes later.* The retardation takes place, not for the maximum distance only, but proportionately for intermediate distances; *i.e.* the eclipses are too late by times which are to 16½ minutes, as the distance of the Earth from Jupiter is to the maximum distance. It is evident, then, that the retardation is due to progressive motion in light, which thus occupies nearly 16½ minutes in travelling across the Earth's orbit, and therefore $8'\ 13''{\cdot}3$ in coming from the Sun to us.

Note.—It follows from the above demonstration, that the position which the sun appears to us to occupy differs from the true one by about 8½ minutes in time nearly, or in space nearly an eighth part of his own diameter; while, since the light of α Lyræ takes nearly 13 of our years to reach the Earth, the apparent position of that star in the heavens will differ from the true one—supposing it to have a proper motion—by the displacement due to 13 of our years.

Note W.

Co-efficient of Refraction and Critical Angle.

If light be passed through a slit in the centre of the diametral plane of a semi-circular box, it may be made to fall on any part of the circular wall.

---

* 16m. 26·6s.

If it be made to fall on either side of the radial line, and the place on which it falls, when the box is empty, noted, it will be seen to fall nearer to the radial line when the box is filled with water; but at points different from this for other liquids. If the circular wall be graduated the relative amount of refraction for different liquids may be noted and tabulated.*

Let the angles of incidence and refraction, found for a given liquid, be CDF, HDG, in the text; then from a point in DC let fall a perpendicular upon FG; and at the same distance along DH let fall another perpendicular on the same line. Let these perpendiculars be p, p' respectively; thus

$$\frac{p}{p'} = \text{the co-efficient of refraction; otherwise}$$

$$\frac{\text{Sin. CDF}}{\text{Sin. HDG}} = \frac{p}{p'}$$

$$\text{If CDF} = 90^\circ, \text{ we have}$$

$$\frac{1}{\text{Sin. HDG}} = \frac{p}{p'}$$

$$\therefore \quad \text{Sin. HDG} = \frac{p'}{p}$$

This is the CRITICAL angle of refraction, and is for water, 48° 35′, and for glass, 38°·41′.

NOTE X.

POSITIVE AND NEGATIVE CRYSTALS.

I. *Positve Crystals.*

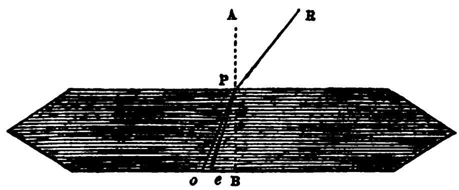
QUARTZ.	TITANITE.
ZIRCON.	ICE.

In this class, to which the crystals here enumerated belong, of the refracted rays, the extraordinary lies nearer to the perpendicular, at the incident point P, than the ordinary, as is shown in the following section

---

* See Muller's Lehrbuck der Physik, 4 Edition, vol. ii. p. 393.

of a crystal of quartz by the plane of the paper, in which plane the incident and refracted rays are supposed to be situated.



Taking i as angle of incidence, APR,

i' „ ordinary refraction, BPo,

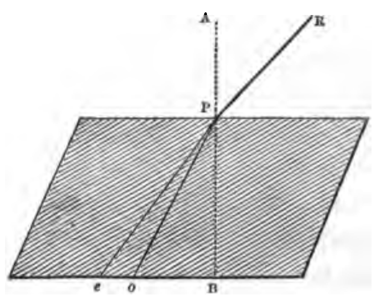
i'' „ extraordinary refraction, BPe.

We have for this class $\frac{\text{Sin. } i}{\text{Sin. } i'} < \frac{\text{Sin. } i}{\text{Sin. } i''}$

II. *Negative Crystals.*

Iceland Spar.	Corundum.
Bitter Spar.	Ruby.
Tourmaline.	Nitrate of Soda.

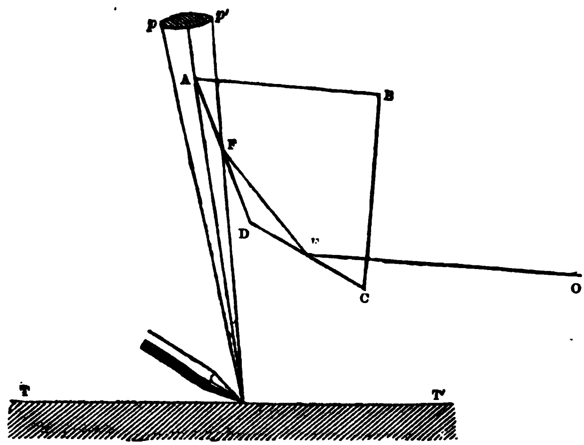
In this class, which is a very extensive one, the extraordinary refracted ray lies farther from the perpendicular than the ordinary refracted ray does, as is shown in the following section of a crystal of Iceland Spar, in which the letters correspond with those in the diagram above.



For this class obviously $\frac{\text{Sin. } i}{\text{Sin. } i'} > \frac{\text{Sin. } i}{\text{Sin. } i''}$

Note Y.

It has been seen, in Note W, that the greatest refracting angle for glass is 38° 41′. If the path of the ray be reversed, therefore, the incident angle, in case of emergence, cannot exceed that quantity. It is found, indeed, that when it does exceed this limit, there is reflection—the most perfect known—within the glass. It is desirable to show here how this fact is availed of in the construction of the Camera Lucida; since many experience difficulty in the use of this elegant little instrument which, otherwise, might find increased employment amongst the eleves of our colleges.



A B C D is a four sided prism, right angled at B, and having the angle ADC 135°, then BAD, BCD, which are equal to one another, will be each 67° 30′.

If a pencil of rays from an object in the direction EO fall perpendicularly on B, it will be incident on DC at an angle which is the complement of OEC, and is, therefore, equal to BCD, hence there will be complete reflection at E. The same will take place at F, and the pencil will finally emerge at, or near to, a right angle from AB, and may be received by the pupil $p\ p'$ of an eye situated as in the figure. An image of the object from which the pencil OE proceeds will therefore be seen in the direction of the table TT′, and may be made to repose on the sheet of drawing paper on which its outline is to be traced.

In the use of the instrument the pupil of the eye should be so placed, that while it views the image of the object through the prism, it may also see the pencil directly. Such instruments are generally provided with lenses, by means of which rays from the image of the object and from the point of the pencil may be made to have the same divergence at their entrance into the eye.

GLOSSARY.*

ABSORPTION. (Lat. *absorbeo*, to suck up). The power or act of imbibing, or drinking up a fluid; as trees by their roots draw up or absorb the moisture of the soil, containing their food in solution.

ACHROMATIC. (Gr. *a*, privative; *chroma*, colour). Without colour; thus telescopes are said to be achromatic, when their field is unfringed by colour.

ACOUSTICS. (Gr. *acouo*, to hear). The science which treats of sounds.

ACTION. (Lat. *ago*, to move). The energy exerted by one body upon another; while the action returned by the latter is termed re-action, the two being equal.

AERIFORM. (Lat. *aër*, the air; *forma*, a form). Having the physical nature of air; such are the gasses generally.

AEROSTATION. (Gr. *aer*, the air; *istemi*, to weigh). Suspension in the air, a name given to the art of traversing or navigating the air by means of balloons.

AFFINITY. (Lat. *ad*, to; *finis*, a boundary). The relationship of one element to another; in Chemistry, the force which produces new compounds from dissimilar elements.

ALCOHOL. (Arabic, *al*, the article; *kohil*, a spirit). The intoxicating principle in spirituous liquors; spirit of wine.

ALKALI. (Arabic, *al*, the article; *kali*, the name of a plant). A substance which neutralizes acidity; such are potash, ammonia, &c.

AMALGAM. (Gr. *ama*, together; *gameo*, to marry). A term signifying the union of a metal with mercury.

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* This glossary is much indebted to that appended to Professor Daniell's excellent work on Chemical Philosophy.

AMBER. (Arab. *umber*, grass). A fossil resin, or gum, produced by an extinct species of pine or fir, in which the attractive power of electricity was first discovered; the gum was so named on account of its possessing the power of attracting small pieces of straw, or grass, when rubbed. Its name in Persian, Khyroba, is analogous to this, meaning the straw-attractor.

ANALOGOUS. (Gr. *ana*, thoroughly; *logos*, a relation). Possessing corresponding relations; or performing corresponding functions.

ANALYSIS. (Gr. *ana*, thoroughly; *luo*, to loosen). The reduction of a whole to its parts; the technical meaning of the word is analogous in Geometry and Physics.

ANTAGONISM. (Gr. *anti*, against; *agonizomai*, to contend). The strife of one force against another; such is the opposition which exists between centripetal and centrifugal forces; also between the attractive and repulsive molecular forces, &c.

ARMATURE. (Lat. *armo*, to arm). A piece of soft iron employed to connect the poles of a magnet, or system of magnets, to prevent their becoming enfeebled.

ASTATIC. (Gr. *astatos*, balanced.) A term applied to a compound magnetic needle, made up of two magnetically equal needles, parallel between themselves, and with their opposite poles adjacent to each other.

ASTRONOMY. (Gr. *astron*, a star; *nomos*, a law). The science which treats of the heavenly bodies.

ATMOSPHERE. (Gr. *atmos*, vapour; *sphaira*, a sphere). The air which we breathe, and which surrounds our globe.

ATOM. (Gr. *a*, not; *temno*, to cut). An ultimate particle of matter, not susceptible of diminution.

ATTRACTION. (Lat. *ad*, to; *traho*, to draw). The tendency of bodies to approach towards each other, or rather the cause, whatever it be, of that tendency.

AURORA BOREALIS.
AURORA AUSTRALIS. (Lat. *aurora*, the morning; *boreas*, the north; *auster*, the south). Brilliant, corruscating, lights seen in high latitudes, *i.e.* towards the north and south poles of the earth respectively.

AUSTRAL. Lat. (*auster*, the south). Pertaining to the south.

BALANCING, sustaining equilibrium. Fair traders balance or weigh their commodities by just and corresponding weights.

Balloon. (Fr. *ballon*, a ball). A spherical bag of silk, or other light material, for containing gas, steam, or smoke, by the buoyancy of which it may be enabled to ascend in the atmosphere.

Barometer. (Gr. *baros*, weight; *metron*, a measuse). An instrument for determining the pressure, or weight of the atmosphere.

Biaxial. (Lat. *bis*, twice; *axis*, an axis). Having two axes. In optics the term is applied to crystals, which have within them two lines similarly surrounded by equal optical powers; in other words, two axes of double refraction.

Bibulous. (Lat. *bibo*, to drink). Having the quality of drinking up, or affording a passage to moisture; such is the sponge, unsized paper, capillary tubes, &c.

Body. An aggregate of molecules, comprehending the solid, liquid, and gaseous forms of matter.

Boreal. (Lat. *boreas*, the north). Northern; belonging to the north.

Bromine. (Gr. *bormas*, stench). A liquid, elementary substance, having a strong pungent odour; it is much used in Photography, on account of the great sensibility to the chemical action of light, which it gives to iodized metallic plates.

Bucket; a wooden or other vessel for containing liquids; also the cells on the periphery of overshot water-wheels.

Calc Spar; named also Iceland spar. Crystallized carbonate of lime, belonging to the rhomboidal class of crystals.

Caloric. (Lat. *calor*, heat). The cause of the sensation of heat.

Calotype. (Gr. *kalos*, beautiful; *tupos*, an impression). A picture produced on paper suitably prepared by the action of light.

Camera Luicida. (Lat.) An instrument for the formation of images of objects; the images being produced by the agency of a prism, and in the light.

Camera Obscura. (Lat.) An optical instrument for the formation of images of objects, by means of a lens; it was originally used in a dark room, hence its name.

Capillary. (Lat. *capillus*, hair). A term applied to bodies having exceedingly fine, or hair-like, bores.

Carbon. (Lat. *carbo*, a coal). The chemical name for charcoal.

Caustic. (Gr. *kaio*, to burn). Possessing the property of burning; a name given, in Optics, to the curve of maximum illumination, by reflected or refracted light.

CENTRIFUGAL. (Lat. *centrum*, a centre; *fugio*, to cause to fly). Acting from the centre; the force which acts in opposition to the Centripetal force, is called the Centrifugal force.

CENTRIPETAL. (Lat. *centrum*, a centre; *peto*, to seek). A force, urging a body towards a centre, is named Centripetal force; such is the force which causes a stone to fall towards the Earth, and the Earth to tend towards the Sun.

CEREALS. (Lat. *ceres*, corn). The different species of grain, the edible part of which is protected by a husk; such are wheat, oats, and the like.

CHOROID. (Gr.) A membrane lining the outer coat of the eye; deriving its name from a fancied resemblance to the exterior investment of the ovum.

CHROMATIC. (Gr. *chroma*, a colour). Of or belonging to colour.

COHESION. (Lat. *cum*, together; *hæreo*, to stick). The relation between bodies, or parts of bodies, which causes them to adhere together.

COMBUSTION. (Lat. *comburo*, to burn). The process of change produced in bodies by burning; as for instance, in wood by the destructive action of fire.

COMPLEMENTARY. (Lat. *compleo*, to fill). That which makes up, or completes a thing; as that which makes up a right angle, in Geometry; or that colour, which, added to coloured light, makes up white light, in optics—thus, red is complementary to green.

CONCAVE. (Lat. *concavus*, hollow). That which is curved inwards; as the interior surface of a cup, or a section of the same.

CONDUCTION. (Lat. *con*, together; *duco*, to lead.). The power of transmission of heat, electricity, &c.

CONGELATION. (Lat. *con*, together; *gelo*, to freeze). The process of freezing; conversion of liquids into solids by cold.

CONSTITUENT. (Lat. *constituo*, to put together). The parts, of which any thing is made up, are said to be its constituent parts.

CONTACT. (Lat. *con*, together; tango, to touch). The mutual relation of two bodies which touch each other.

CONVEX. (Lat. *con*, together; *veho*, to carry). Curved outwardly.

CORNEA. (Lat. *cornu*, a horn). The transparent clear membrane of the eye, which covers and protects the Iris and Retina.

CORPUSCULAR. (Lat. dimin. of *corpus*, a body). Relating to atoms.

Couronne des Tasses. (Fr.) Crown of cups. A name given, by its contriver, to a voltaic arrangement, on account of its fancied resemblance to a crown.

Cryophorus. (Gr. *kruos*, cold; *phero*, to produce). An instrument for showing the effect of evaporation on temperature.

Crystal. (Gr. *krustallos*, ice). Substances having regular forms, and frequently transparent like ice.

Daguerreotype. The art of taking pictures by the agency of light on metallic surfaces; called Daguerreotype in honour of Daguerre, its inventor.

Decomposition. (Lat. *de*, from; *compono*, to compound). The resolution of a compound body into its constituent elements.

Deflagration. (Lat. *deflagro*, to burn). Burning with corruscations of light, as in the case of wire, or plates of metal, burned by galvanic fire.

Deflection. (Lat. *de*, from; *flecto*, to bend). The turning aside of something from its path; as the magnetic needle, by the electric current, in Oersted's experiment.

Deliquiscence. (Lat. *deliqueo*, to melt). The melting of a substance by absorption of moisture.

Detonation. (Lat. *detono*, to thunder). Explosion accompanied with noise.

Diagram. (Gr. *diagrapho*, to delineate). A representation by drawing; as the pourtrayal of propositions, and demonstrations, by figures.

Dia Magnetic. A term applied by Professor Faraday to bodies which, under magnetic influence, take up positions at right angles to those assumed by magnetic bodies.

Diaphanous. (Gr. *dia*, through; *phano*, to shine). Through which light can pass.

Diaphragm. (Gr. *dia*, separation; *phrasso*, to shut up). A separation between two things; a stop emploped in telescopes, &c. to intercept a portion of the light.

Dielectric. (Gr. *dia*, through; *electron*, electricity). That through which electricity may be transmitted.

Differential. A minute difference.

Differential Thermometer. A thermometer for the detection of very small differences of temperature.

Diffraction. (Lat. *de*, from; *frango*, to break). The breaking or bending of rays of light from their straight course, which occurs on their passing the edge of an opaque body.

Dipping Needle. A magnetic needle or bar, free to move in a vertical plane; an instrument for showing the direction of the magnetic pole.

Disc. (Gr. *discos*, a round plate of metal). A round surface, as that of the moon.

Disintegration. (Lat. *de*, separation; *integer*, the whole). The resolution of a whole into its parts.

Dispersion. (Lat. *de*, apart; *spargo*, to scatter). The act of scattering; in optics, the spreading out of homogeneous light.

Distillation. Separation drop by drop. The process of separating one fluid from another, by converting it first into vapour, and then recondensing it.

Diverging. (Lat. *de*, from; *vergo*, to turn). The turning aside from a given direction or position.

Ebullition. (Lat. *ebullio*, to boil). The act of boiling.

Economic. (Gr. *oikos*, a house; *nomos*, a rule). Having practical application to the wants or elegancies of life.

Electricity. (Gr. *electron*, amber). A power, general in nature; first detected in amber, and hence its name.

Electrode. (Gr. *electon*, electricity; *hodos*, a way). The points at which the electric current rises or sets—the zinc and copper elements of the ordinary galvanic pair.

Elasticity. (Gr. *elaono*, to thrust back). The power inherent in many bodies of recovering their shape, or volume, when deprived of either by violence; it is familiarly seen in India-rubber.

Electrolysis.
Electrolite. (Gr. *electron*, electricity; *luo*, to decompose. The process of disuniting compounds by means of electricity. The substance acted upon is termed the Electrolite.

Electrometer. (Gr. *electron*, electricity; *metron*, a measure). An instrument for determining the quantity and quality of electricity in any body.

Electrophorus. (Gr. *electron*, electricity; *phero*, to produce). An instrument for producing electricity.

Electroscope. (Gr. *etectron*, electricity; *scopeo*, to view). An instrument for detecting and testing free electricity.

ELEMENTARY. (Lat. *elementum*, an element). Not susceptible of reduction.

EMANATION. (Lat. *e*, out; *mano*, to flow). That which issues out from any thing; as light from a radiant point.

EMPIRICAL. (Gr. *en*, in; *peiraomai*, to make trial). That which is said or done as an experiment merely; the expression of an experiment.

EQUATOR. (Lat. *aequus*, equal). The plane, in any body, equally distant from both its poles, and perpendicular to its polar axis; such as the celestial equator in Astronomy, the terrestrial equator in Geography, the magnetic equator in Physics, &c.

EQUILIBRIUM. (Lat. *aequus*, equal; *libra*, a balance). The dynamic result of balancing forces.

EQUIVALENT. (Lat. *æquus*, equal; *valeo*, to be worth). Equal in value.

ETHER; (Lat.) the pure air. An exceedingly subtle and elastic fluid, supposed to pervade all space.

EVAPORATION. (Lat. *e*, out; *vapor* vapour). The conversion of a liquid into vapour; as the ascent of moisture, from the Earth's surface, into the atmosphere.

EXHAUSTION. (Lat. *exhaurio*, to draw out). The removal of a fluid; as the removal of air from within the receiver by an air-pump.

EXPANSION. (Lat. *expando*, to open out). The increase in the bulk of bodies, due to heat; in Geometry, development into the form of series.

EXPERIMENT. (Lat. *experimentum*, a trial). Something done, in order to discover an unknown effect; also, less accurately, the repetition of such operations.

EXPERIMENTUM CRUCIS. (Lat.) A conclusive experiment, which, like a cross or finger post, guides to truth.

EXPLOSION. (Lat. *ex*, out; *plaudo*, to burst). The sudden expansion of a fluid, accompanied with sound; as when gunpowder, confined in any way, is ignited.

EXTRAORDINARY. (Lat. *extra*, out of; *ordo*, order). Unusual; in Optics, that branch of a doubly refracted ray of light, which lies in a plane, making an angle with the plane of ordinary refraction.

FILTER. A strainer for separating the grosser from the more fluid parts of bodies; the operation of separating solid ingredients from liquids.

FLUIDITY. (Lat. *fluo*, to flow). That condition of matter in which, as in air or water, the particles move freely among each other.

Focus. (Lat. *focus*, a fire-place). A centre from which rays of light, or heat, emanate; or in which they are condensed.

Formula. (Lat.) A general theorem.

Friction. (Lat. *frico*, to rub). The rubbing of the surfaces of bodies upon each other.

Fringes. (Fr. *frange*, a border). Bright and dark lines bordering an image or shadow, and produced by interference of light.

Fulcrum. (Lat.) A point of support, a prop; as the point about which a lever turns.

Fusion. (Lat. *fundor* to be melted). The state of reduction, from a solid to a fluid state.

Galvanism. Electricity by contact; so named in honor of Galvani, who first detected the manifestation of the power, in the convulsions of the limbs of a frog.

Galvanometer. (*Galvanism; metron*, a measure). An instrument for measuring galvanic electricity.

Gas. An æriform fluid: such are Oxygen, Nitrogen, and Carbonic acid, the component gases of the atmosphere.

Genus. (Lat.) A whole race or kind.

Gravitation. (Lat. *gravis*, heavy.) The force which draws bodies towards each other; as the attraction of the sun, which draws the planets towards him.

Gravity. (Lat. *gravis*, heavy). The tendency of bodies to fall towards an attracting centre.

Gymnotus Electricus. A fish of the eel tribe, possessing the power of giving a strong electric shock.

Halo. (Gr. *halos*, a crown). A luminous circle, appearing occasionally round heavenly bodies.

Heat. The science which treats of the properties, laws, or effects, of caloric.

Heliographic. (Gr. *helios*, the sun; *grapho*, to delineate). A term sometimes applied to the art of making pictures by the agency of light—the synonym of Photographic.

Helix. (Gr. *helisso*, to twist round). The worm of a screw; a spiral.

Hemisphere. (Gr. *hemisus*, half; *sphairo*, a sphere). A half sphere, formed by a plane through the centre of the sphere; thus, the two portions of the earth cut off by the equatorial plane, are called North and South Hemispheres.

HERMETIC SEAL, (the seal of Hermes). Glass or metallic vessels, sealed by fusion, of the aperture, are said to be hermetically sealed.

HETEROGENEOUS. (Gr. *heteros*, different; *genos*, kind). Made up of constituents, differing in nature and properties.

HOMOGENEOUS. (Gr. *homos*, like; *genos*, kind). Being the same in nature and properties throughout: in Physics, a sphere of uniform density is said to be homogeneous; if it be not so, it is termed heterogeneous.

HYDRAULICS. (Gr. *hudor*, water; *aulos*, a pipe). That branch of physics, which treats of the mechanical properties of fluids in motion.

HYDROGEN. (Gr. *hudor*, water; *gennao*, to produce). The lightest known substance, and the base of water.

HYDROMETER. (Gr. *hudor*, water; *metron*, a measure). An instrument for measuring the relative densities of liquids.

HYDROSTATICS. (Gr. *hudor*, water; *statos*, standing). The branch of Natural Philosophy which treats of the equilibrium and mechanical properties of fluids.

HYGROMETER, HYGROMETRY. (Gr. *hugros*, moist; *metron*, a measure). An instrument for determining the amount of moisture, present at any time, in the atmosphere. The art of determining the amount of moisture in the atmosphere, or in gases generally, is called Hygrometry.

HYPOTHESIS. (Gr. *hupo*, under; *tithemi*, to place). A principle taken for granted, in order to prove a point.

IMPINGING. (Lat. *impingo*, to strike against). Coming into contact with; two solid bodies in motion are said to impinge against each other, when they come into collision.

INCANDESCENT. (Lat. *incandesco*, to grow white.) White, or glowing with heat.

INCIDENCE. (Lat. *in*, upon; *cado*, to fall). The direction in which one body strikes another, as referred to a perpendicular to the surface impinged upon.

INCIDENCE—angle of. Direction of contact of one body with another.

INCREMENT. (Lat. *incresco*, to increase). The quantity by which any thing is augmented; thus the increase of size of a metallic bar, due to heating, is the increment of volume of the bar.

INDUCTION. (Lat. *in*, to; *duco*, to lead). The process of reasoning which ascends from particular to general truths.

INERTIA. (Lat. *inertia*, inactivity). The tendency of matter to continue in the same state, with respect to rest or motion.

INFLECTION. (Lat. *in*, to; *flecto*, to bend). A bending or turning aside of any thing from its path.

INSULATION. (Lat. *insula*, an island). The surrounding of a body by non-conducting bodies, so as to preserve it in a given state.

IODINE. (Gr. *ion*, a violet; *eidos*, likeness). An elementary substance, the vapour of which is of a violet colour; it is much used in photography, on account of the sensibility to light imparted by it to metallic plates.

IRIDESCENT. (Lat. *iris*, the rainbow). Exhibiting the prismatic colours. Like a rainbow.

IRIS. (Lat. *iris*, the rainbow). The circle surrounding the pupil of the eye; which owes its name to its beauty of form and colour.

ISOCHRONOUS. (Gr. *isos*, equal; *chronos*, time). Performed in equal times; the oscillations of pendulums, describing small arcs, are said to be isochronous, they being performed in equal portions of time.

LAMINÆ. (Lat. *lamina*, a thin plate). The thin plates or films, of which some bodies, such as mica, are composed.

LENS. (Lat. *lens*, a bean). A piece of glass or mineral crystal, so formed that rays of light are, by passing through it, made to change their course in a determinate manner.

LEVIGATION. (Lat. *levis*, light; *ago*, to bring to). The separation of the fine portions of a heavy body, by suspension in water and pouring off.

LEYDEN JAR. A glass vessel, coated within and without with tinfoil; so named because it was first invented at Leyden in Germany.

LIQUEFACTION. (Lat. *liquefacio*, to make liquid). The process of conversion of a solid into a liquid, as of ice into water.

LOADSTONE. (Swed. *Load-star*, the Pole-star.) A natural magnet; an ore of iron possessing attractive properties, which is named, in consequence, magnetic iron ore.

LUMINOUS. (Lat. *lumen*, light). Producing or displacing light.

MAGNET. (Magnesia, a town in Asia Minor). A bar of iron possessed of the property that, when free, it takes up a position coincident, or nearly so, with the meridian.

MAGNETISM. That branch of physical science which treats of the construction and properties of the magnet.

MALLEABLE. (Lat. *malleus*, a hammer). Susceptible of being spread out by beating, such are gold, silver, &c.

MAXIMUM. (Lat. *maximus*, greatest). The greatest value attained by any given variable.

MECHANICS. (Gr. *mechane*, a machine). The science which treats of the nature and laws of the motion, or rest, of bodies.

MENISCUS. (Gr. *mene*, the moon). A lens, concave on one side and convex on the other, like a new Moon.

MERIDIAN. (Lat. *meridies*, the mid-day). A great circle, passing through the poles of the earth and a given place.

MICROSCOPE. (Gr. *mikros*, small; *scopeo*, to view). An instrument for rendering small objects visible, and thereby subjecting them to examination.

MICA. (Lat. *mico*, to shine). A simple mineral of bright silvery lustre, a constituent of granite.

MINIMUM. (Lat. *minimus*, least). The least value which a given variable attains.

MIRROR. (Fr. *miroir*, a looking-glass). A polished surface, such that images of objects are formed by rays of light reflected from it.

MOLECULE. (Lat. dim. from *moles*, a mass). A group of atoms.

MONAS TERMO. (*Monas*, an unit; *termis*, a maggot). The most minute and simple of microscopic animalcules, shaped like spherical cells, and considered by Buffon, the element of organized beings.

MOMENTUM. (Lat. *moveo*, to move). The force of a moving body.

MOULDING; fashioning into any required shape; as in the formation of images out of clay.

NASCENT. (Lat. *nascor*, to be born). The condition of being produced, or pertaining to that condition.

NITROGEN. (Gr. *nitron*, nitre; *gennao*, to produce). One of the gases constituting the atmosphere, and a constituent of nitre.

NORMAL. (Lat. *norma*, a rule). According to rule: in Geometry, the perpendicular to a curve, or surface.

NUCLEUS. (Lat. *nucleus*, a kernel). The centre of aggregation of a body; situated in it as the kernel is, in a nut.

OPACITY. (Lat. *opacus*, dark). The optical state of a body, through which light cannot pass.

OPTICS. (Gr. *optomai*, to see). The science which treats of the nature and properties of light.

ORGANIC. (Gr. *organon*, an organ). Bodies are said to be organic, when they possess the powers necessary for self support and continuation of their species.

OSCILLATION. (Lat. *oscillor*, to swing). The motion of a pendulum, or motion corresponding thereto.

OXYGEN, (Gr. *oxus*, acid; *gennao*, to produce). An æriform fluid; one of the component gases of the atmosphere, and of water; also constituting a considerable portion of the ponderable matter of which the earth is made up.

PELLICLE. (Lat. dim. from *pellis*, a skin). A thin film, forming occasionally on the surfaces of fluids; such as is produced by letting a drop of oil of turpentine fall into water.

PENDULUM. (Lat. *pendeo*, to hang). A heavy body, so suspended that it may swing backwards and forwards in an assigned curve.

PENUMBRA. (Lat. *pene*, almost; *umbra*, a shadow). The imperfect shadow that surrounds the true one; to it is due the incomplete obscuration, which precedes and follows an eclipse of the sun and moon.

PERCOLATE. (Lat. *per*, through; *colo*, to strain). To pass through a filter.

PERIOD. (Gr. *peri*, round; *hodos*, a way). The interval between the recurrence of the same event; as the time between two perihelion passages of the same planet.

PERMEATE. (Lat. *permeo*, to pass through). To pass into or through a body.

PHENOMENON. (Gr. *phainomai*, to appear). An appearance.

PHOSPHORUS. (Gr. *phos*, light; *phero*, to carry). An inflammable, elementary substance, which burns with low combustion in the atmosphere, emitting light.

PHOTOGRAPHY. (Gr. *phos*, light; *grapho*, to write). The art of delineating or drawing by the agency of the chemical properties of light.

PHOTOMETER. (Gr. *phos*, light; *metron*, a measure). An instrument for comparing the intensities of light.

PHYSICS. (Gr. *phusis*, nature). The science which treats of matter, its modifications, and the phenomena occurring in and by it.

PILE. (Fr. *pile*, a heap). A voltaic arrangement in which a number of plates of two dissimilar metals are heaped upon each other in pairs.

PISTON. (Fr.) A plug, sometimes perforated and provided with a valve, the office of which is to exhaust the air from tubes.

PLUMMET. (Lat. *plumbum*, lead). A weight, suspended by a string, to determine the vertical; the weight being, in the rudimentary form of the instrument, usually of lead.

PNEUMATICS. (Gr. *pneuma*, breath). The branch of Natural Philosophy which treats of the weight, elasticity, &c., of gaseous bodies.

POLARISATION. The possession of different properties by the opposite sides of a ray of light, conferred by refraction through certain media, or by reflection at a certain angle.

POLARITY. (Gr. *polos*, the pole). The opposition of forces or properties; as during electric and magnetic tension, there are two points, opposite to each other, possessing equal forces but of different properties.

POLLYGASTRIC. (Gr. *polus*, many; *gastron*, a stomach). A class of animalcules, having many stomachs.

PORES. (Gr. *poros*, a passage). The interspaces between the constituent particles of a body; as those for instance, in water, into which particles of salt or sugar are received and disappear.

PROJECTILE. (Lat. *pro*, forward; *jacio*, to throw). Something propelled or thrown forward, as a stone from a sling, a bullet from a gun, &c.

PUMP. (Fr. *pompe*). A machine for raising liquids, from lower to higher levels.

PYROMETER. (Gr. *pur*, fire; *metron*, a measure). An instrument for determining high degrees of heat, and the expansion of solid bodies thereby.

RADIATION. (Lat. *radius*, a ray). The emission of rays of heat, or light, from a centre; as of light and heat from the sun.

RAREFACTION. (Lat. *rarus*, rare; *facio*, to make). Diminution of density; as in the case of air, on being heated.

RAY. An elementary beam of light, a number of which, united together, constitute a pencil.

RECTIFICATION. Preparation and refinement by distillation.

Reflection. (Lat. *re*, back; *flecto*, to bend). Repulsion from a surface; in Physics, "the angle of reflection is equal to the angle of incidence."

Refraction. (Lat. *re*, back; *frango*, to break). The breaking or bending aside of a ray of light, towards, or from, a perpendicular to the surface at the point of incidence, in passing from one medium into another less or more rare, respectively.

Retina. (Lat. *retina*, a net). The delicate net work covering the interior surface of the eye; and which is formed by expansion of the optic nerve.

Retort. (Lat. *re*, back; *torqueo*, to bend). A vessel with a bent neck, used in distillation.

Rotation. (Lat. *rota*, a wheel). The act of turning round upon a point or line, as a wheel about its axle.

Salts. Combinations of acids with a metallic or organic base.

Saturation. (Lat. *satur*, full). The solution of a body in a fluid, till the latter can take up no more of it.

Scale. (Lat. *scala*, a ladder). An instrument accurately divided into parts, for measurement of dimension.

Sclerotic. (Gr. *skleros*, hard). The outer coating of the posterior part of the eye, terminating anteriorly in the cornea, and posteriorly in the sheath of the optic nerve.

Section. (Lat. *seco*, to cut). The division of a body by cutting; a portion so cut off; thus, the surfaces made by cutting a cone, in certain directions, are called the Conic Sections.

Solar. (Lat. *sol*, the sun). Belonging to or having relation to the sun; thus, spots in the sun are called "solar spots;" a circle of light about the sun, a solar halo.

Solution. (Lat. *solvo*, to loosen). A mixture made up of a solid and fluid, in which the former disappears.

Specific. (Lat. *species*, a kind; *facio*, to make). That which pertains to an individual, or to all comprised under the term.

Spectrum. (Lat.) The appearance of a ray of white light when refracted through a triangular prism.

Spontaneous. (Fr. *spontane*, of its own will). That which occurs, or is produced, without artificial aid.

Statics. (Gr. *statos*, standing). That branch of science which treats of bodies at rest.

STEREOSCOPE. (Gr. *stereos*, solid; *scopeo*, to view.)

STRATUM, pl. *strata*. (Lat. *sterno*, to strew). A layer; the different coats, composing the earth's crust, are so called.

SYMBOL. (Gr. *sumbolon*, a type). A figure, employed for brevity, to represent a name or formula.

SYMMETRICAL. (Gr. *sun*, together; *metron*, a measure). Uniformity of measure, or arrangement; the two portions of a circle made by its diameter, are symmetrical with reference to that diameter.

SYNCHRONOUS. (Gr. *sun*, together; *chronos*, time). Occurring at, or in the same time.

SYPHON. (Gr. *suphon*, a tube). A bent tube, used for transferring liquids from one vessel to another.

TANGENTIAL. (Lat. *tango*, to touch). The condition of a line or plane meeting, but not cutting, a curve or surface.

TELEGRAPH. (Gr. *tele*, at a distance; *grapho*, to write). A contrivance for making communications at a distance; such is the Electric Telegraph.

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UNIAXIAL. (Lat. *unus*, one; *axis*, an axis). Having but one axis; in Optics, crystals, in which light is polarized about one axis only, are called uniaxial.

VACUUM. (Lat.) An empty space; such as the Torricellian vacuum in the barometer tube.

VALVE. (Lat. *valva*, folding doors). A lid, or stop, opening in one direction; employed in pumps to prevent the escape of fluids back towards their source.

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VORTEX, pl. VORTICES. (Lat.) A whirlpool; rotation of fluids about an axis, as seen in the dust raised by a whirlwind.

WHIRL. (Ge. *wirbeln*, to turn quickly round). To cause a body to move rapidly round an axis or centre.

ZERO. (Arab. *tsaphara*, nothing). The symbol occupying the position between the positive and negative, the ascending and descending, scales of numbers.

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